metal treatment

Vol. 27 : No. 183 DECEMBER, 1960 Price 2/6

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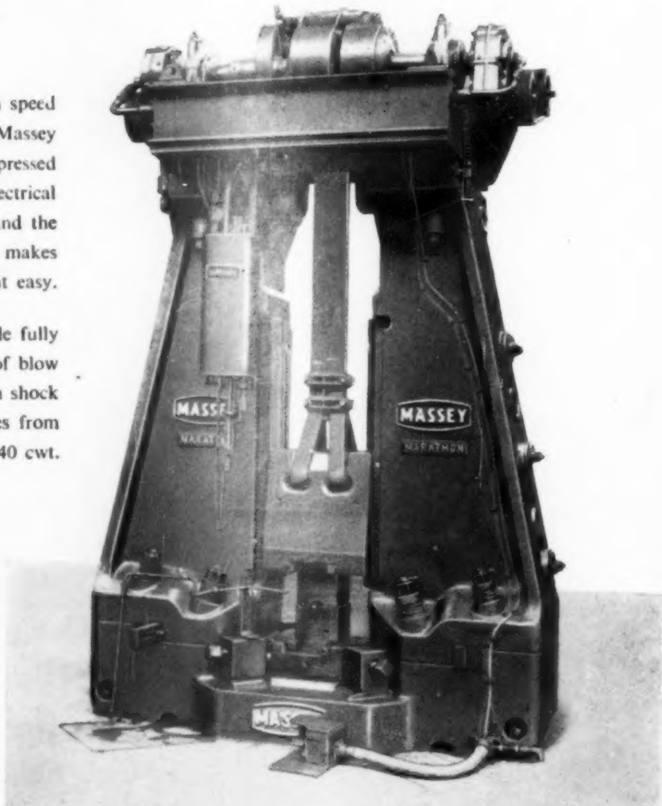

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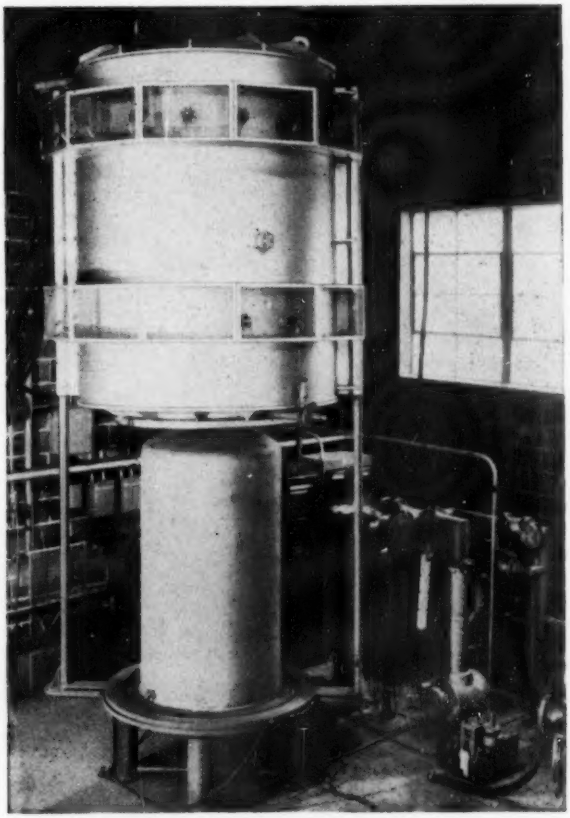

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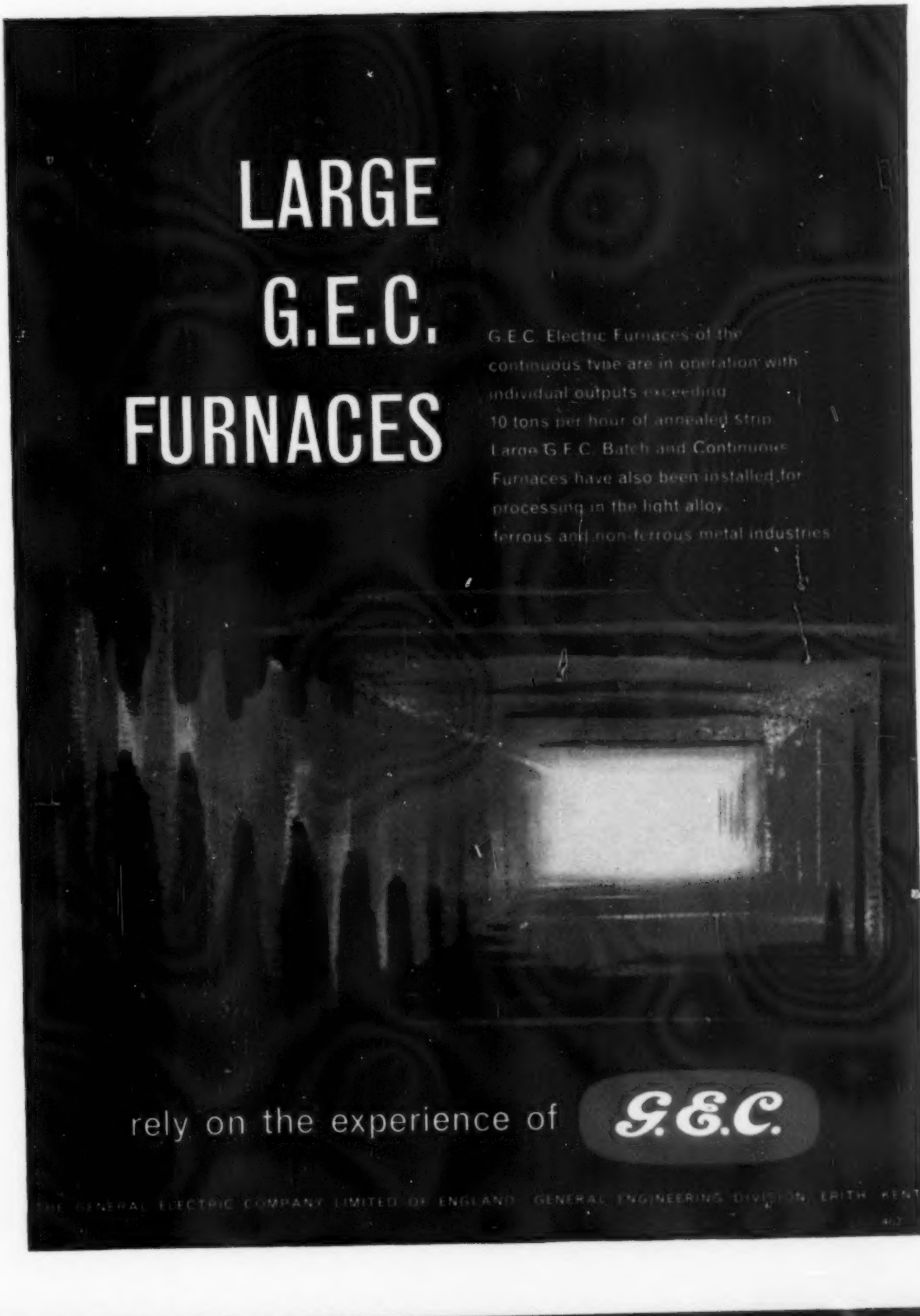
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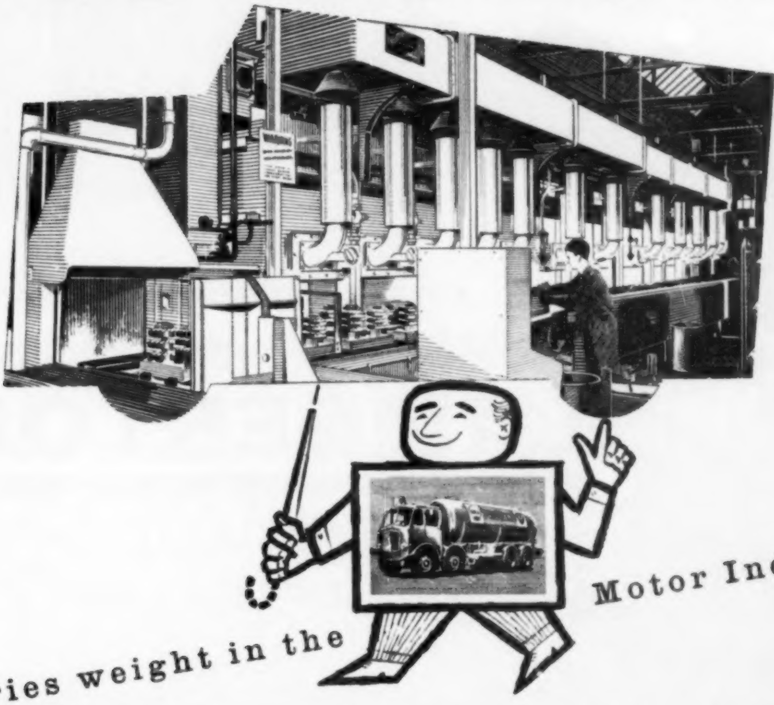

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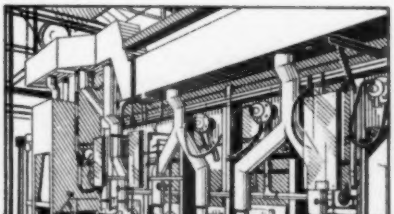

These illustrations, by courtesy of Ford Motor Co. Ltd, show two of many continuous gas carburizing furnaces installed at their Dagenham factory, using endothermic atmospheres produced from PROPAGAS.

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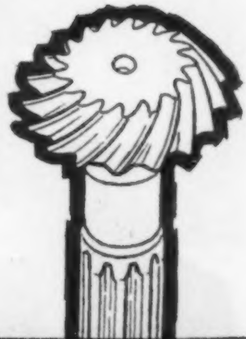

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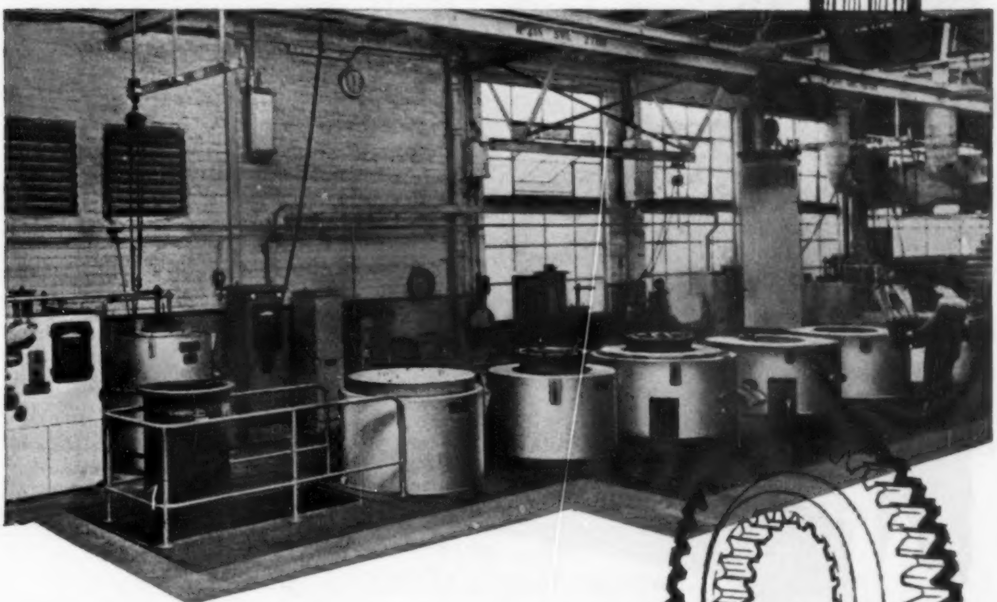

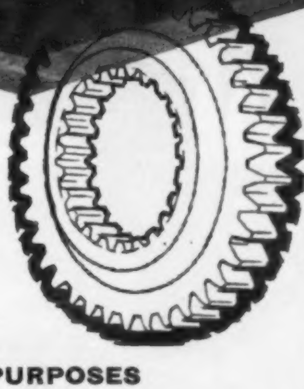

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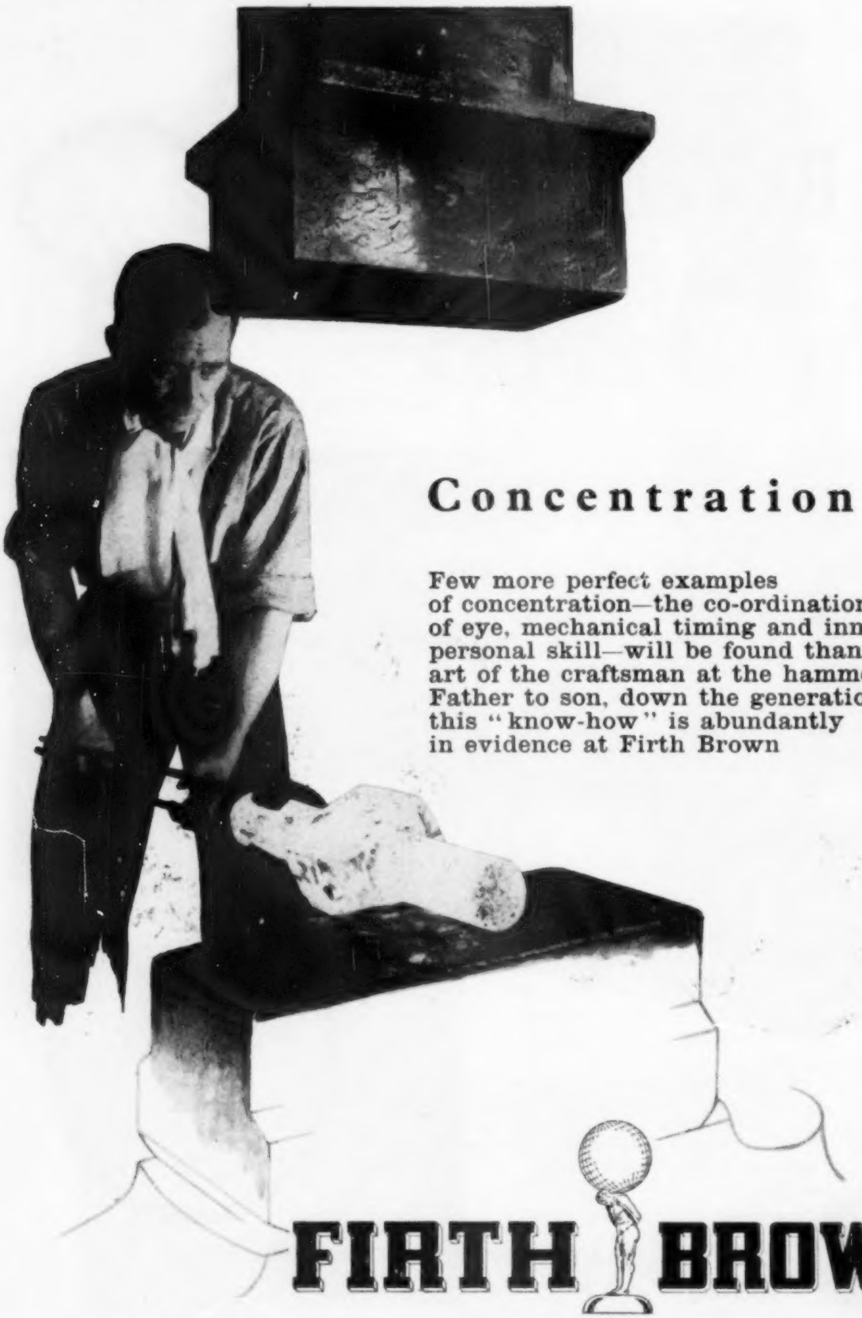

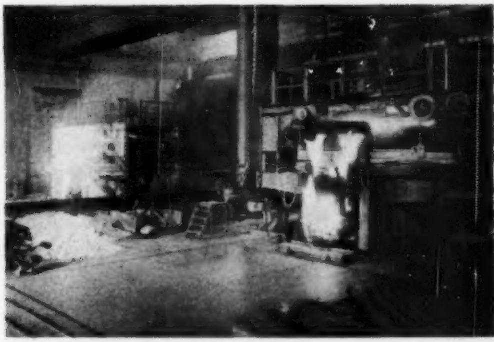

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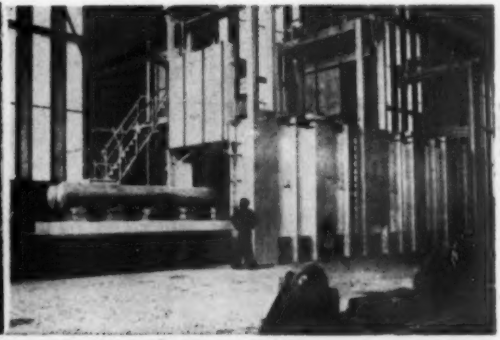

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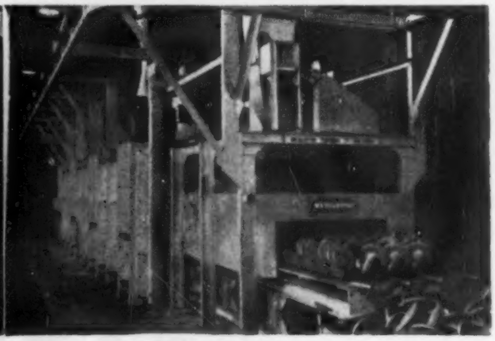

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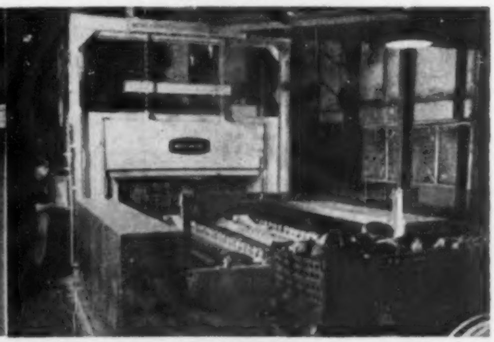

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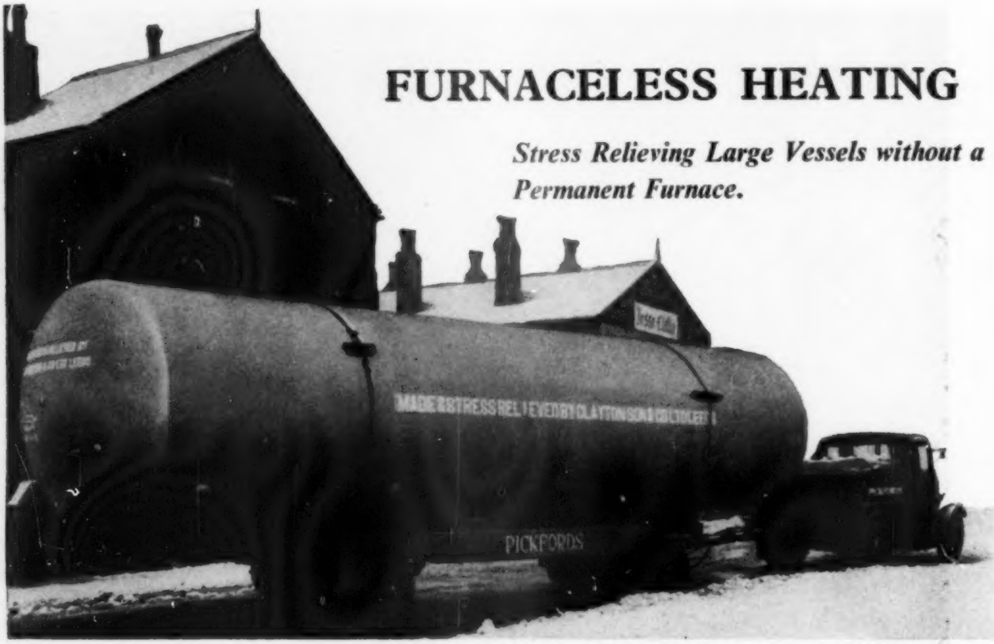


FURNACELESS HEATING

Stress Relieving Large Vessels without a Permanent Furnace.

Fig. 1. 46′ x 9′ diameter high pressure cylinder, stress relieved *in situ*.

Clayton Son & Co. Ltd., of Leeds have been well known as heavy engineers for nearly 100 years and one important aspect of their business is the fabrication of large welded pressure vessels. Recently they received an order for two high pressure propane gas cylinders, one of which is shown in Figure 1. These are of all-welded construction and to comply with British Standard 1500, dealing with stress relieving of pressure vessels after welding, the whole of the vessel must be heated after fabrication according to an extremely exact time/temperature schedule. When the stress relieving temperature of the vessel is at 650°C, the temperature differential between any two points must not exceed 50°C.

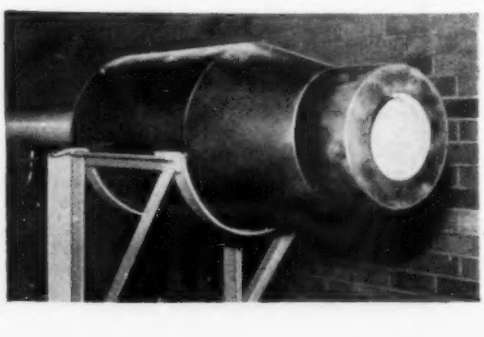
The usual method of meeting these requirements is to place the pressure vessel in a gas-heated furnace and raise its temperature in accordance with the requirements of B.S. 1500. However, as the dimensions of the vessels increased—the gas cylinders mentioned above being 46′ x 9′ in diameter—the number of stress relieving furnaces available for this class of work was limited. Sometimes the job had to be done by inserting one end of the container into the furnace with the other end protruding, and then reversing it. This was obviously uneconomical in terms of fuel and hardly met the real requirements of B.S. 1500.

Messrs. Claytons discussed their problem with the Industrial Development Centre of the North Eastern Gas Board, and they undertook experiments with high velocity jet type gas burners, working on an old Lancashire boiler shell. Within six months, the North Eastern Gas Board had evolved a method of stress relieving these larger containers *in situ*, obviating the inconvenience and expense of transporting the vessel to another factory for the stress relieving to be carried out. This stress relieving process is covered by a joint patent held by the North Eastern Gas Board and Clayton Son & Co. Ltd.

A model of the equipment used is shown in Figure 3 and the burner is shown in Figure 2.

First the whole of the vessel was lagged with an insulating material which in this case was 4″ of Rocksil. The jet burner was then arranged to fire through the manhole of the vessel into a hot gas distribution tube arranged internally, having a number of perforations, as shown in Figure 4. The hot blast of gas through the central distribution tube causes, by entrainment, the recirculation of waste gases within the centre tube, distributing the heat uniformly throughout the vessel. In addition, arrangements were made for jets of compressed air to control the hot gas flow from the ends of the distribution tube to provide uniform heating at the ends of the vessel. Finally, the hot gases escape

Fig. 2.
High velocity jet type gas burner.



through the same vent through which the burner fires, as shown in Figure 4. Since it is necessary to record the temperature of the vessel at points not more than 15 feet centres, steel blocks were welded to the vessel and carried the thermocouple wires. A continuous record of the vessel temperature was maintained over the heating and cooling periods and experience seems to indicate that the temperature schedule can be maintained even more accurately than is at present required by the B.S. Actual records obtained are shown in Figure 5. The following data give some idea of the performance achieved in the stress relieving of the high pressure cylinder shown in Figure 1.

Dimensions of Vessel

Length..........Approximately 46 ft.
Diameter..........................9 ft.
Plate thickness....⅞" shell, 1" endplates
Access hole..18" diameter, 6 ft. from end
Weight........Approximately 21 tons

Burner Dimensions

Overall length.....................28"
Exit port..........................4½"
Air supply pressure................40"
Air capacity available......1000 c.f.m.
Gas max. capacity....7000 cu. ft. per hr.
Jet speed (tunnel exit)....
Approximately 400 m.p.h.
Recirculating tube........15" diameter
Discharge holes....3"—3½" dia. holes along its length with 6"—9" end discharge.

Operational Details

Normal heating rate..7 hrs. to reach 600°C
Average gas rate..4200 cu. ft. per hour

The thermocouple readings over the period under investigation are given in Figure 5 and the inspecting authorities showed a great interest in the process, which they thought to be an improvement over prevailing methods. It is of interest to note that the Rocksil lagging cost about £280 with an additional £75 for its application and the installation of the centre tube. It is thus obvious that stress relieving of large vessels can now be carried out at minimum capital cost by fabricators without furnaces, eliminating transport to furnace plant with freight charges estimated at no less than £1 per ton per mile.

This is of course, only one practical application of furnaceless heating. The North Eastern Gas Board and Messrs. Clayton Son & Co. Ltd. are experimenting with the erection of a temporary furnace which might be likened to a form of Nissen hut in sheet metal. This is lagged with Rocksil, and irregular shaped articles of large tonnage may be placed inside this canopy. Once again a central tube arrangement is used, the jet burner being so placed that the whole of the irregular shaped component may be uniformly heated. Such a furnace is to be built by Messrs. Claytons.

The North Eastern Gas Board is also using this for the drying out and heating up of large glass furnaces after they have been repaired or rebuilt. Here again is an instance where the time/temperature schedule must be rigorously controlled because of the various physical and chemical changes which occur in the furnace brick work during drying out and pre-heating periods. The summarised advantages of furnaceless heating include:

- *a* Minimum capital cost.
- *b* It is no longer necessary to occupy permanent factory space with a huge furnace.
- *c* Reduced running costs.
- *d* The advantages of stress relieving *in situ*.

The North Eastern Gas Board is convinced of the importance of the applications of the principle of high velocity jet type burners for many heat treatment processes without using a permanent furnace structure. Typical applications include pressure vessels for the chemical and oil refinery industries as well as those employed in nuclear energy projects. This is one example only of the manner in which the Industrial Development Centres of the Gas Boards undertake work on behalf of and in co-operation with manufacturers. Their experiences are interchanged so that any manufacturer approaching his Industrial Gas Engineer has the benefit of this co-ordinated knowledge of applied industrial gas techniques.

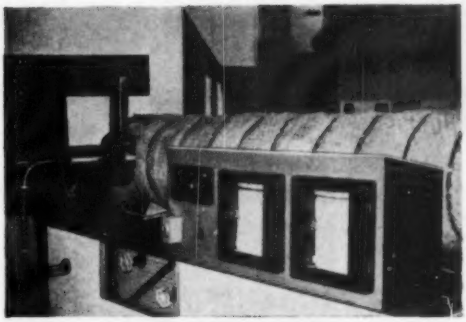


Fig. 3. Model of equipment used in furnaceless heating process.

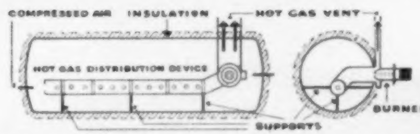


Fig. 4. Diagrammatic section through lagged cylinder showing burner jet and distribution tube.

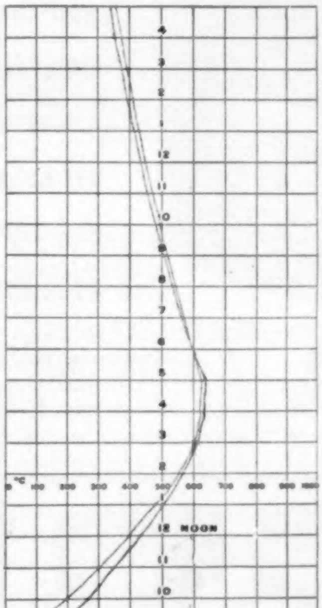


Fig. 5. Continuous temperature recording of heating and cooling process. (Maximum and minimum curves of the 12 points recorded).

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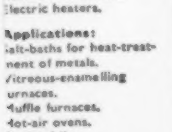

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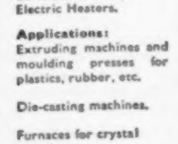

TYPE 991:
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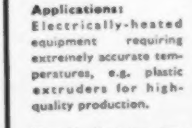

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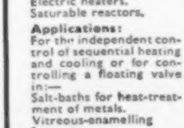

TYPE 993:
Three-position (employing any combination of the preceding control systems).

Operating:
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Contactors. Relays.
Electric heaters.
Saturable reactors.

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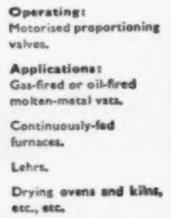
Vitreous-enamelling furnaces.
Muffle furnaces.
Crucible furnaces.
Extruding machines.
Moulding presses.
Die-casting machines, etc., etc.



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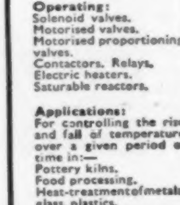

TYPE 994:
Time-Temperature (employing any one of the preceding control systems).

Operating:
Solenoid valves.
Motorised valves.
Motorised proportioning valves.
Contactors. Relays.
Electric heaters.
Saturable reactors.

Applications:
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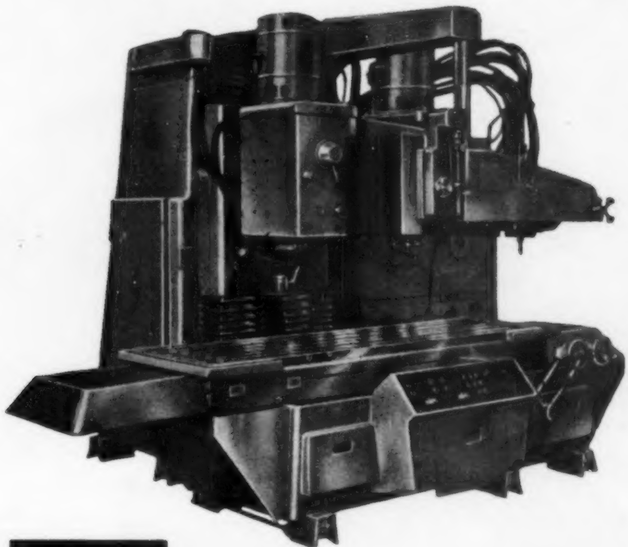

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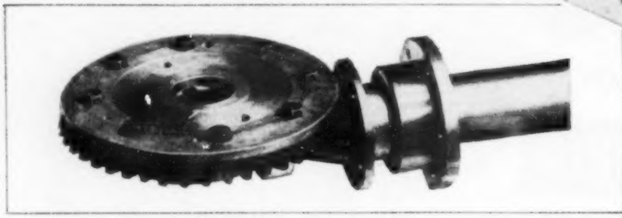

Bevel pinion and crown wheel assembly for gathering head.

Economical coal production depends upon rapidly removing coal or stone when it has been brought down. To do this the Samson Loader has been developed by Mavor and Coulson Ltd., Bridgeton, Glasgow, S.E.

The Samson Loader is essentially a flexible conveyor on to which two gathering arms quickly pull loose material. The delivery end of the jib can be varied from 2 ft 1 in to 8 ft 4 in high, and peak capacity working for Model MC3 is up to 5 tons of coal per minute.

To achieve reliability under the difficult conditions in coal mines, the designers specified nickel alloy steels notably En25, En36B and En24 or equivalents for high impact values. These steels are used for gear shafts and other components.

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2½ in. dia.	Oil quenched 830°C. tempered 650°C.	58	63	21	68
4 in. dia.	Oil quenched 830°C. tempered 650°C.	56	61	21	69
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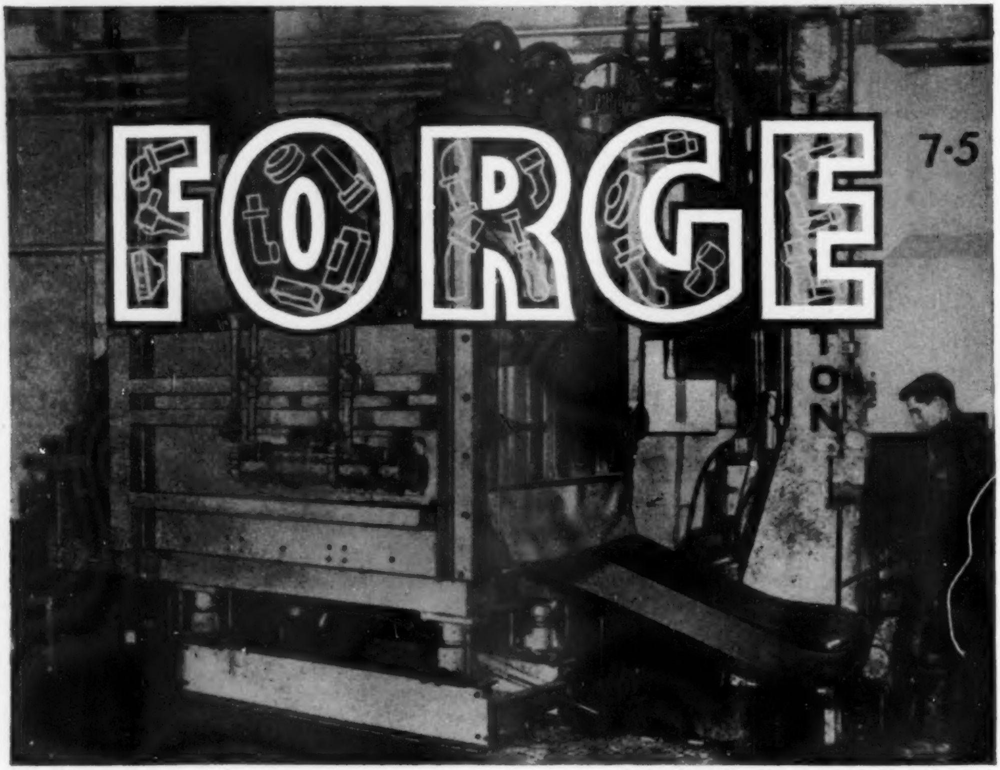

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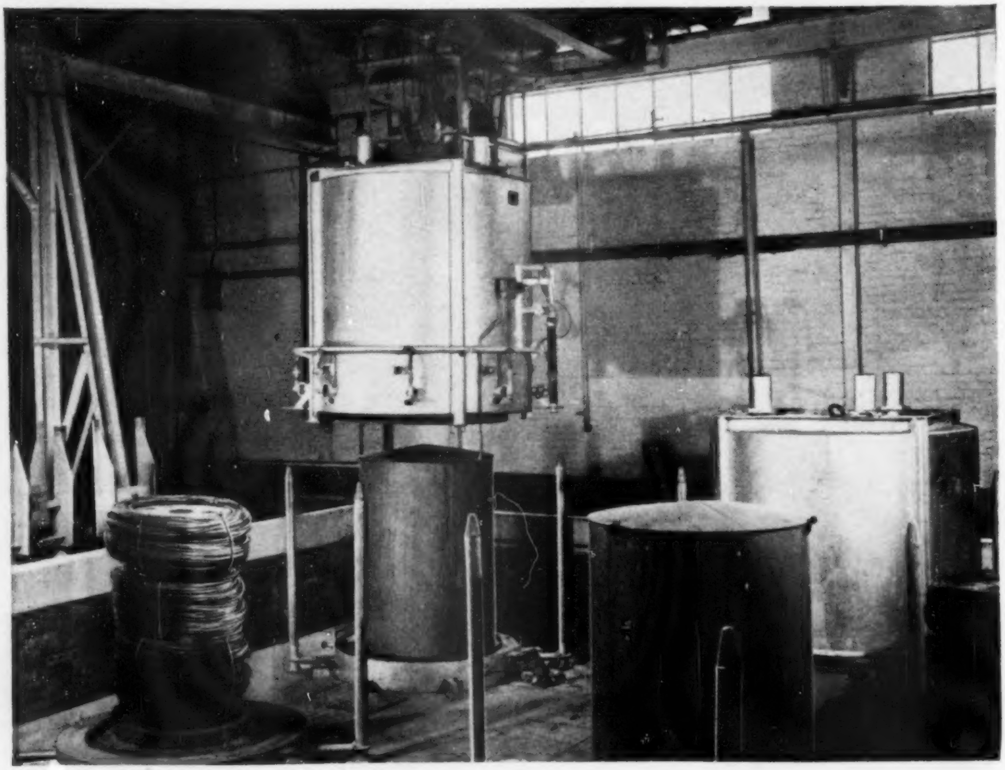

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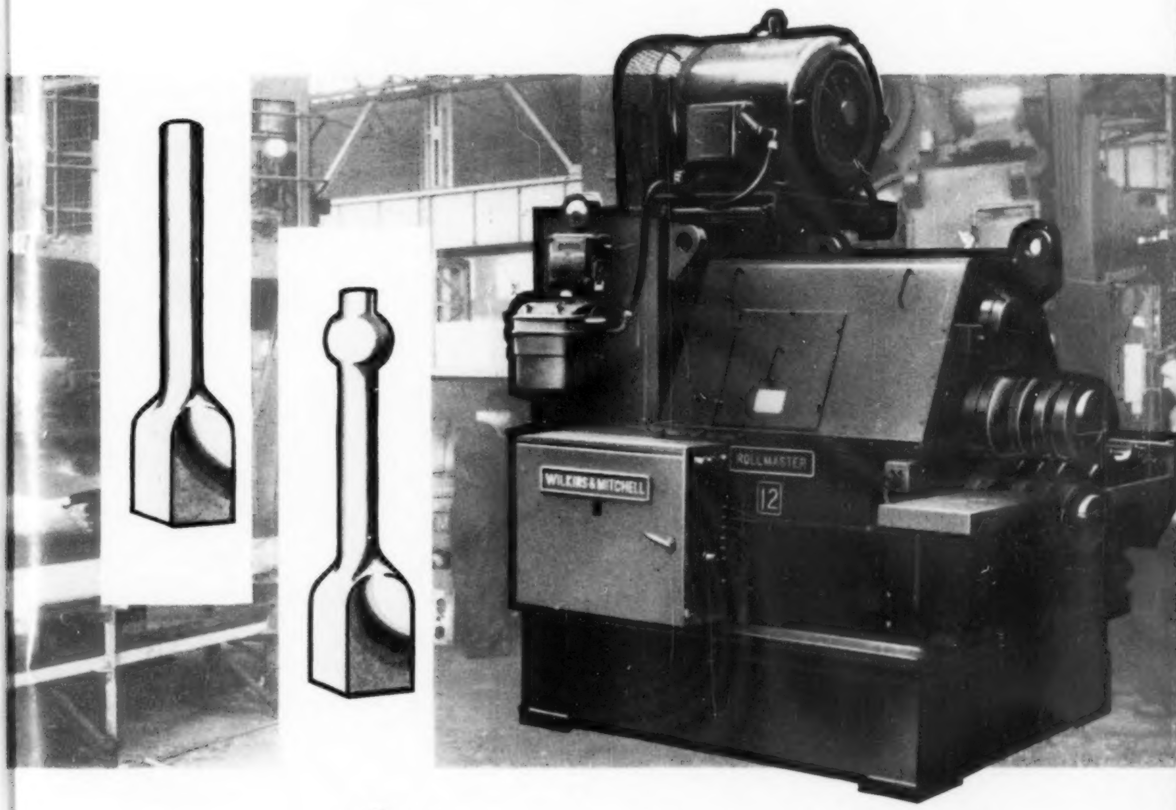

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metal treatment

and Drop Forging

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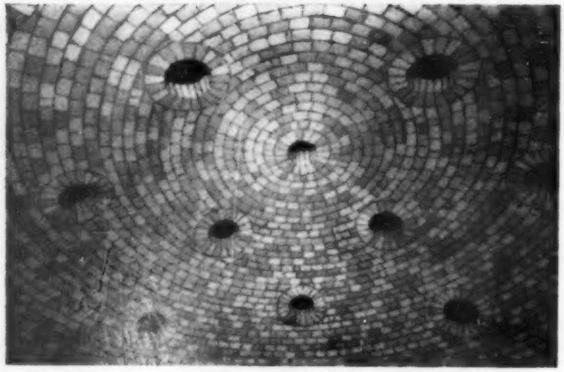
CONTENTS

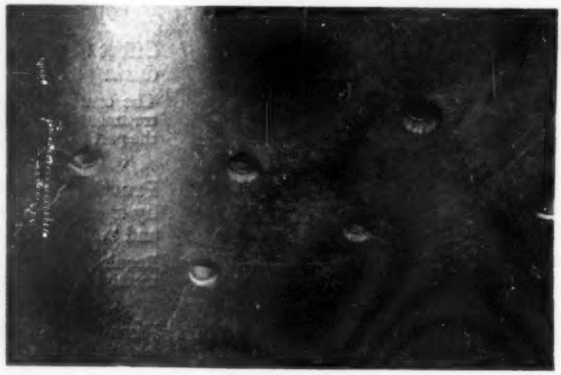
This journal is devoted to metals—ferrous and non-ferrous—their manufacture, properties, heat treatment, manipulation, testing and protection, with research work and development in all these fields

We
take our own
medicine



Five years ago we began rebuilding the round down-draught kilns of The Morgan Crucible Co. Ltd. at Battersea in MI. 28—a hot-face insulating brick of low thermal capacity that was then comparatively new. The roof of one of these furnaces immediately after installation is shown in the first picture.

. . . (MI. 28 bricks)
. . . and like it



The output of these kilns, lined with MI. 28, was considerably greater than their firebrick counterparts, because the low heat-storage of the lining shortened both heating and cooling periods. This, in fact, was the principal reason for the change-over. What we were not so sure of at that time was the life of these linings. We would hardly have dared to expect anything as good as we got. The second picture shows the same roof after *five years* service. So far as we can see it is good for at least another five years and probably longer.

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Drop forging today

IT is commonplace to say that the traditional industries are highly resistant to change—of course they are, that is why they are traditional. It is also true that in many ways they are quite justified—changes indulged in just for the sake of novelty can easily prove costly and irrevocable. Nevertheless, nothing can remain in the same place indefinitely, and a constant watch is needed to maintain close contact with changing conditions both inside and outside the plant. It is all too easy to take for granted that what worked well yesterday will also work well enough tomorrow, when, in fact, investigation may show that it has already ceased to work today. In other words, it is essential to be able to detach oneself from a customary viewpoint and to look and see what is actually happening. ' We have always done it this way, do I know why? Is it still the best available method?' . . . etc.

It is clear that such critical detachment is exceedingly difficult when immersed in the day-to-day running of a plant, and it is becoming more and more usual to employ specialists and specialist organizations to ensure that the highest possible efficiency is being achieved. Last month, at the National Association of Drop Forgers' and Stampers' Technical Convention at Droitwich, drop forgers took part in discussions with experts in different fields, some of whom serve industry by examining existing methods and proposing possible future improvements.

One of the lecturers, Mr. E. Tholander, Sveriges Mekanforbund, aroused great interest with an excellent exposition in English of examples of forging research in Sweden. He gave a picture of the industrial and historical background of the forging industry in Sweden, and described the Forging Laboratory at Eskilstuna with details of its research equipment. In view of the proposed co-operative drop-forging research organization in this country, details of the Swedish experience were particularly interesting. Mr. Tholander then described a particular research on the forging process with open and closed dies. Upsetting of cylinders in the drop hammer and the factors affecting closed die forging were being studied by means of lead specimens at room temperatures with much greater facility than would be possible with hot steel.

A quite different aspect was highlighted by Mr. G. H. Simmons, S. J. Noel-Brown & Co Ltd., who spoke on the need for greater productivity. Stressing the value of work study in industry, Mr. Simmons said that work measurement enabled management to organize, control and direct human activity towards specific ends by applying techniques designed to establish the time for a qualified worker to carry out a specific job at a defined level of performance. Method study was the systematic recording and critical examination of present and proposed ways of doing work, to develop easier and better methods and to reduce costs. These were the twin techniques of work study.

Other interesting papers given at the conference were by Mr. E. C. Seed, Cowlishaw, Walker & Co. Ltd., on ' present trends in the design of power presses ' and by Mr. J. P. Wilson on ' the influence of the cost accountant on productivity.' We came away from the conference feeling that we had been shown some of the necessary tools for maintaining an industry in a competitive position. The tools are there waiting—all that remains is to make sure that good use is made of them.

Basic features of the cold forging process

A. M. COOPER, A.M.I.Prod.E.

'Modern trends in the manipulation of metals' was the theme of a conference held at Brighton last October by the Institution of Production Engineers. Among the techniques discussed, precision forging was very much to the fore, and we hope to give other papers presented at the conference on this subject in future issues. Mr. Cooper is with the Experimental Department, G.K.N. (Midlands) Ltd.

THE UBIQUITOUS woodscrew and the rivet are typical products of the cold-forging process—a process where the starting material is round wire and components, in general having axial symmetry and a head formed on a smaller-diameter shank, are formed continuously at high speed. A study of modern cold-forging techniques will show, however, that it is a process well suited for the manufacture of many kinds of components currently made by other methods.

Unfortunately, cold forging is a process in which practical development has proceeded at a faster rate than the basic research work has followed, and there is a scarcity of published technical information on the subject. Perhaps it is because of this state of affairs that designers and engineers have tended to neglect the potentialities of the process through a lack of knowledge of the type of plant used and the basic elements of design for cold forging.

Hence, this paper is intended, for those unacquainted with the cold forging, to be an introduction to the basic features of the process and to provide some information on the elements of design for it.

Cold-forging machines

Special-purpose horizontal mechanical presses are used for cold forging. Although these machines, fitted with automatic feed and cut off, are known as cold-headers, the term is misleading, as it is possible to upset portions of the shank of the wire in addition to forming the head.

There are several basic types of forging machines and these can be classified according to the following characteristics:

1. *The type of heading die.* Two die types are recognized and each requires a specific machine design. The split die header, which is known also as the open die header, uses a die made up from a pair of rectangular blocks, each with matching semicircular grooves extending down the length of the block. The solid die header uses a die which is a simple cylinder with a hole extending down the longitudinal axis; more normally, this die will be made up from a pre-stressed cylindrical case and an insert.

2. *The number of heading blows available within the cycle of operations.* The majority of cold-headers are either single-blow or double-blow machines. A single-blow header applies the heading punch once during the cycle, *i.e.* a component is forged for each revolution of the flywheel; *i.e.* a component is forged for each stroke of the punch ram. The double-blow header, fitted with an indexing punch header containing two separate punches, applies each of the punches once during the cycle, *i.e.* two complete strokes of the ram are required to produce one component.

There are few machines which have been designed to provide three blows—three punches but three revolutions of the flywheel per component. This type of machine is not in common use, as the decreasing ductility of the upset material tends to reach a limiting figure when forging with a single die. Due to this limiting factor, a modified form of header, known as a transfer header, has been developed. This machine is, in reality, a series of single-blow, single-die headers, each linked to the next by means of a transfer mechanism, and all contained within one frame. Thus, this convenient arrangement of dies permits a progressive reduction of the wire diameter to be undertaken and the multi-tool arrangement allows more complex forms to be achieved. As each operation is carried out simultaneously, a finished component can be produced with every stroke of the header.

3. *The maximum diameter of wire which can be used on the particular header.* Cold-heading machines are designed to operate within certain specified wire-diameter ranges and it is common for a machine to be known by the maximum wire diameter it can handle and not by its available power, *e.g.* $\frac{1}{8}$ in., $\frac{3}{16}$ in., $\frac{1}{4}$ in., $\frac{5}{16}$ in., $\frac{3}{8}$ in. and $\frac{1}{2}$ in. The design limitation is not only in the available

power, but it is also in the size of the die pockets and the strength of the cut-off mechanism.

4. *The maximum length of wire which can be cut off at each cycle of operations.* Heading machines are designed also to operate within specified lengths of cut-off. (It should be noted that the cut-off length includes all the material to be upset into the head as well as the material to form the shank.) Thus, for every machine, there will be an absolute minimum and an absolute maximum cut-off length and the resultant shank length will be dependent upon the volume of material which is to be upset into the head. As a general rule, the minimum cut-off length is considered to be about three times the wire diameter and, for solid die forging, a maximum about 12 times the wire diameter. However, special long-stroke machines are designed to operate between roughly eight times wire diameter up to 20 times wire diameter.

It will be shown later that the split-die header can be capable of handling a cut-off length of up to 30 diameters.

Exceptionally long work is usually forged in specially designed open-die headers, sometimes known as spoke headers, where the frame is cut away to facilitate either manual or semi-automatic feeding.

Cold-forging sequence of operations

The basic sequence of operations is essentially the same for all types of headers but as there is a difference between the operation of a split-die and a solid-die header, both sequences are described here.

Solid-die header. In the case of a single-blow solid-die header, wire is fed from the coil by automatic feed rolls, through a cut-off die, up to an adjustable stop. The stop is so arranged as to cause a predetermined length of wire to protrude in front of the cut-off die. A cut-off knife slides across the face of the cut-off die and shears off the predetermined length of wire; the slug is retained in the knife, by a hinged finger. The motion of the cut-off knife is continued so as to transfer the slug to a position in line with the heading die bore. The heading punch is advanced and pushes the slug part-way into the die, *i.e.* until the insertion is prevented by a plunger pre-positioned inside the die bore. The cut-off knife and finger in the meantime have released the slug and they return to a position in front of the cut-off die.

The pre-positioning of the plunger causes a determined amount of the slug to remain protruding in front of the die and it is this portion of the slug which is upset by the continuing forward motion of the heading punch. Initially, the whole of the compressive force is exerted on the end of the plunger but, as soon as the slug begins to upset, the thrust is distributed across the newly formed surfaces against the face of the die. Any tendency for the shank to swell and bind in the bore of the die is thereby limited. Consequently the wire is formed to the shape of the cavity in the heading punch and/or in the face of the die. The heading punch is withdrawn and the plunger is caused to move forward, thereby ejecting the headed blank from the die.

With this arrangement, components having the same head form and shank diameter, but different plain shank lengths can be accommodated by adjusting the amount of wire cut-off and adjusting the position of the plunger in the die bore within the design limits of the header. The maximum slug lengths which can be fed into a ‘ closed ’ die and, after upsetting, ejected from the die is normally equivalent to about 12 wire diameters. The length is limited not only by the frictional forces involved but also by the relative clearances around the various moving parts at the carryover, feed and ejection stages in the cycle.

Split-die header. The split-die header uses a die made up of two rectangular blocks, so arranged that one block can be moved a small distance laterally relative to the other (*i.e.* the die can be opened slightly at the beginning and at the end of the cycle) and the die as a whole can be moved laterally relative to the machine frame.

In the case of the single-blow split-die header, wire is fed from the coil in between the blocks in their open position (*i.e.* from the rear of the blocks) up to an adjustable stop. The die blocks then close, the movement of one block towards the other shears off the predetermined length of wire and then clamps the slug. It should be noted that the rear face of the block acts as the cut-off knife. The die as a unit continues to move laterally to bring the slug in line with the punch and, at the same time, to bring the rear face of the die in front of a solid portion of the frame. The punch then moves forward to upset the protruding portion of the slug. As the punch withdraws the die returns to the starting position and the blocks separate slightly. Thus, as the wire is fed in for the next cycle, the end of the wire acts as an ejector for the headed blank.

It will be seen that with the split-die header, each shank length requires a specific length of die due to the fact that the rear face of the die registers the end of the shank. However, since the split die is open during wire feed in and during ejection, the length is limited only by the machine design (and by the ability to pre-straighten the wire).

It should be noted that, although a powerful clamping mechanism is used, the characteristic feature of the split-die header is the slight witness of the division between the two die blocks on the under-surface of the head of the blank. The blocks

tend to wince, or separate, slightly under the full heading load and the material is forged into the gap.

Two-blow machines. With the two-blow machines, the sequence of operations is as described above except that the blank is retained in the die after the first blow has been applied. As the first heading punch is withdrawn, the punch block is indexed so as to bring the second heading punch in line with the die. The second blow is applied and the blank ejected in the normal manner. The wire feed and cut-off mechanism is arranged to operate only once during the cycle.

Transfer headers. In the case of transfer headers, the design is based on the solid-die method. These machines are sometimes called progressive headers, as the blank, after each forging stage, is ejected into transfer fingers and carried over to the next station. Thus a number of head forging and/or shank-reducing operations can be carried out simultaneously and a finished component is produced at each stroke of the machine. It is usual for the machine to have three, four or five forging stations and the final station can be adapted to trim, or shear, a cheese-headed blank to a square or hexagon form.

Cold-forging limitations

Upset ratio. As the upsetting force is an axial compression, there is a limited length of unsupported wire (protruding from the die) which can be upset at the beginning of the process without buckling, *i.e.* this is a classic example of the Euler Theory of Struts. For successful forging the material must upset evenly and flow in controlled directions; properly controlled grain flow is the factor chiefly responsible for the superior strength of cold-forged components compared with components produced by machining from bar stock. Thus, one of the important factors to be considered, when assessing a component for its 'forgeability,' is the upset ratio. This is the ratio between the length of wire required for upsetting into the head shape to the original diameter of the cut-off wire. As the ratio is increased, there is an increased tendency for the wire to buckle and, as a consequence, unsatisfactory grain flows will be obtained within the finished forged head.

Practical experiment indicates that the maximum possible length which may be upset in one blow cannot normally exceed 2·3 times the wire diameter.

If it is required to upset ratios greater than 2·3, and not more than 4·5, the total upset must be shared between two blows. Clearly the second punch and the die form must correspond exactly to the size and shape of the finished component; the shape of the first blow punch being determined by the needs of the process and not by the design requirements of the finished shape.

It is usual for the first blow punch to be designed so that it gathers the wire into an approximately conical form. The design of this conical form tends to be critical, but the principle is to support part of the wire in the back of the punch and to start the material swelling outward so that, when the finish punch is applied, the material will continue to flow in the desired direction.

The upset ratio is influenced by the practical design of the finished shape and the achievable ratio may be less than the theoretical maximum—for example, large-diameter heads and non-concentric heads, due to the manner in which the material will flow. To a smaller extent, the ratio will be influenced by the surface condition of the wire, and the lubricant which can be used, when the effect of imperfections (for example, any tendency to cracking) imposes physical limitations on the amount of the upset.

As three-blow headers are not commonly found, it is usual to obtain upset ratios of greater than 4·5 by partially forming the head shape on a standard two-blow header and then finish forge on a reheader. A reheader is a normal header adapted for magazine feed; this arrangement permits any interprocess annealing which may be required for these larger upsets. An alternative method of obtaining upset ratios of greater than 4·5 is to forge on a transfer header but, in this case, it is usual to use wire stock of a larger diameter than for the two-blow reheader method. The use of a larger wire diameter will reduce the actual working upset ratio and the transfer header tool arrangement permits the larger diameter to be reduced to the final desired shank diameter.

Difficulties are encountered when forging very low upset ratio heads (*i.e.* heads with only a small degree of deformation) since the small force required for upsetting may be insufficient to remove irregularities in the cut-off slug. Additionally, any volumetric variation in the cut-off slug will be reflected to a greater degree in heads of small volume.

Larger-diameter thin heads tend to provide the worst forging conditions. There is always the tendency for material to burst in the regions of maximum displacement, *i.e.* around the outer circumference. This is especially so when there are discontinuities in the surface of the original wire, *e.g.* wire-drawing scores, laps and surface slag. In addition, the actual deformation of material tends to be non-uniform.

For example, expansion becomes non-uniform due to the friction of compressed surfaces and to the internal effects of material work-hardening. These factors can be minimized by reducing the compressive surface friction (by effective lubrication) and by selecting material which has a good surface finish

free from inclusions. Thus, where the component shape requires large mean deformations the material should be capable of good deformability, but if the component shape requires high maximal deformations, then the material must have a good surface finish, *i.e.* there is a definite relation between material stress and material content.

Hence the degree of deformation (the ratio of the cross-sectional area of the upset part to the cross-sectional area of the original wire) must be taken into account as well as the upset ratio. The degree of deformation can be conveniently expressed as a logarithmic relationship, *i.e.* $\log_e A1/Ao$. When the value for $\log_e A1/Ao$ approaches a limiting value of about 2, normal two-blow methods produce unsatisfactory deformations and it is necessary to resort to transfer-header methods.

An example of how this criterion can be used is given here. On a two-blow machine the starting material is shank diameter and the wire is extruded to thread-rolling diameter while the head is forged to a cheese shape. If the degree of deformation of the unextruded portion of the shank is zero, the value of $\log_e A1/Ao$ for the head is about 1·5 and the value for the extruded shank is about 0·25. By re-routing to a transfer header, the starting material can be larger than shank size. At the first station a portion of the slug is extruded to shank size; at the second station a portion of the extruded shank is re-extruded to thread-rolling diameter while the head is forged from the original wire diameter to a cheese shape. The degree of deformation for the head is about 1·2, for the plain shank is about 0·4 and for the thread-rolling shank the value is about 0·6. Hence the head is less work-hardened and the degree of work-hardening over the whole blank has been made more uniform.

It is possible by this type of re-routing to produce satisfactory components without resorting to inter-process heat treatment.

Length. There are three dimensions along the longitudinal axis which must be considered—the overall length of the finished component, the length of the part of the component in the die and the cut-off length. These must not be confused. The minimum length in the die should not be less than approximately the wire diameter in use, but this is dependent upon the head volume and the head style.

This limitation is due to: (*a*) The difficulty of holding a relatively short length of slug in front of the die for sufficient time to allow the wire to enter the die (and thus be located) and yet permit the carryover mechanism to withdraw in time to avoid contact with the advancing punch. The usual remedy is to employ an especially thin cut-off knife and carryover finger but this tends to give an insecure grip of the cut-off slug.

(*b*) The frictional forces between the die bore and the parallel part of the shank in the die tend to a minimum and to be less than the frictional forces between the wire and punch. There is then a tendency for the punch to pull the blank from the die and so cause a jab. Various devices are employed to defeat this tendency; for example, the bore of the die can be 'ringed' so that shank material is forged into the ring and causes a lock to occur between the shank and the die. The maximum cut-off length is determined by the design of the header required for forging the component.

Extrusion is the term used when the wire diameter is reduced by forcing the wire through a conically formed extrusion ring contained within specially designed heading dies. It is an operation which can be carried out while the slug is being forged or it can be carried out as a secondary operation, for example, by the use of a reheader.

An extrusion die is designed to have a bore diameter slightly larger than the slug or blank diameter and this diameter bore extends as far into the die as this larger diameter is required. A conical form connects this larger diameter to an extruding ring which has a diameter equal to the reduced shank diameter required, and the ring extends into the die by about 0·030 in. Beyond this ring extends a hole whose diameter is greater than that of the ring by about 0·002 in.

There are limitations to the use of extrusion as a means of obtaining a very accurate shank diameter (which is usually required for thread rolling) and as a means of saving material and time (compared with other methods such as turning and grinding to obtain a similar reduction). These limitations are that:

(*a*) It is necessary that, for normal cold-forging machines the extrusion die must have a conical form leading to the extruding ring. The cone angle will usually be about 30° included but variations of this angle are possible (usually between 20° and 45°). Hence, the profile of the component will repeat the conical form of the die shape, but this cone can be removed by the use of secondary operations if a square shoulder is essential.

(*b*) The degree of deformation by extrusion in one die has a maximum value of about 30% reduction in area, based on the area of the original blank entering the die. Greater reductions are possible by repeating the extrusion process in another die, *i.e.* on a reheader or by the use of a transfer header.

(*c*) Due to the high loads imposed on the extruding ring, tool lives tend to be relatively low when compared to the life of a plain hole die. However, when large numbers of components are concerned, the use of carbide tooling maintains a low unit cost.

(*d*) Not all materials are capable of being extruded successfully, as extrusion depends on the ductility factor and the ability for the tool design to provide adequate support if the material is soft. By suit-

able techniques it is possible to extrude soft copper and aluminium alloys, etc.

(*e*) There tends to be a limit on the length of the extruded portion, determined on one hand by the stroke of the header and on the other hand by any tendency for the extruded shank to be bent on ejection. Bent extruded shanks are not a common feature but they can occur more especially on long lengths. It is considered that tool accuracy is the essential requirement and tool standards must be of the highest order. Special tooling can be used when the extruded length is longer than the plain part length, *e.g.* by using deeper extrusion rings or by using double extrusion rings spaced apart to give the maximum support during ejection.

It is interesting to note that, because wire for extrusion is often phosphate-coated to reduce the frictional forces involved, a definite surface layer is formed during extrusion. This surface is a work-hardened surface but it will have a very small depth of roughness, which can be as low as one micron surface finish, and compares very favourably with the finish obtained with other forms of reduction.

Underhead forging. It has been mentioned previously that extrusion and upsetting of the head can be carried out simultaneously. It is also possible to increase the diameter of the shank immediately underneath the head.

This enlargement can be round, square or even non-concentric. However, the volume of this additional shoulder must be included in the length of wire required for upsetting when calculating the upset ratio.

If the underhead forging is to be a square, it must be realized that absolutely sharp corners cannot be achieved by direct forging. The corners of the square will always be slightly rounded. This effect can be minimized by forging on a split-die header and arranging for two diametrically opposed corners to coincide with the divisions of the die. Other limitations are that the length of the square should not exceed about 60% of the maximum wire diameter for the machine, and that 1° per side draft should be expected.

Forged ribbing is sometimes used as an alternative to a square neck or to lugs where the application is one where resistance to turning is required. Forged ribbing tends to be less costly than knurled ribs formed in a secondary operation. However, the amount of ribbing is limited to about one wire diameter in length and the degree of 'filling out' is dependent upon the head shape and the raw material in use. The cross-section of the ribbing should be such that the form is self-relieving.

Radii. Square inside corners on load-carrying components are areas of stress concentrations. Round corners allow for a smooth transfer of stresses and fortunately the formation of a radius is a characteristic of the cold-forging process. If a sharp corner is necessary, it can be obtained by means of reheading or another secondary operation. If the shank is to be stepped, it is more convenient to design in a taper at the step.

Hence rounded corners are desirable for two reasons—they tend to improve the strength of the component and their inclusion reduces the cost of the component. Radii should be as large as is practicable and, as a general rule, a radius of 5% of the wire diameter is quite possible to forge.

Points. It is usually impossible to obtain a complete cone point by forging—although it can be obtained by other methods, for example, pinch pointing and special pointing attachments. The shape of a forged point is that of a truncated cone, due to the essential requirement of a flat end for ejection purposes.

The limiting factors to the forging of a forged point are that: (*a*) Only solid-die machines can be used.

(*b*) In the case of single-die machines, the shank must be a plain diameter, *i.e.* two extrusions cannot be performed within the single die.

(*c*) The reduction in area at the point should not exceed 30%, and the cone angle not more than about 45° included.

(*d*) As the diameter of the die plunger (*i.e.* the ejector) will be the size of the small end of the point, the strength of the plunger is somewhat reduced and there will be a limit to the maximum length of material which can be ejected from the die. This is a function of the length/diameter ratios for the plunger and the frictional forces involved. For example, only about eight diameters of wire can be ejected for shank diameters below 0·100 in.—provided that the minimum diameter of the small end of the point is not less than 0·060 in.

A forged point can be forged on an extruded shank by indirect means, *i.e.* by the transfer header method. In this case, a point is forged on the slug in the first station die and a register of this point can be retained throughout each of the subsequent operations including extrusion.

Materials for cold forging

It is fair to state that almost any material can be cold forged—provided that proper care has been exercised in the design of the tools and the selection of the forging method. The cold-forging process, however, sets certain limits on the material to be forged if the cycle of operations is to be continuous and, at the same time, successful. The choice of material for cold forging is governed by the often conflicting interests of ease of forming and the required properties of the finished component.

It will be seen, therefore, that the ideal circumstances for forging exist when the choice of material

is left to the manufacturer. It is sufficient for the designer to specify the physical and mechanical properties that he requires from the finished component; any additional information on the application of the component would be of great use in the selection of the manufacturing route.

The most commonly used material is carbon steel for it has the merit of being low in cost, and it is easily and cheaply worked. The lower the carbon content the greater the ductility and the lower the load required to deform the material. Increased carbon content will allow a stronger final product. The basic principle in utilizing low-carbon steel is one of increasing the strength of the material by cold working and, hence, obtaining a fair strength from a very cheap material, but there are limits to the total amount of cold work practicable.

Cold-heading wire is produced by cold-drawing hot-rolled rod. The effect of cold drawing on tensile strength, reduction in area and elongation can be shown. As reduction is increased, the strength of the material is increased but the ductility is reduced. The amount of prior work-hardening by cold drawing is limited in order that the ductility of the material is not reduced to a degree whereby the required upset cannot be attained.

Worked parts require a heat treatment to restore some degree of ductility. This may be a low-temperature stress-relieving treatment, a normalizing or a full annealing treatment.

This involves some loss in strength, depending on the temperature of the particular treatment involved. While the necessity for a process anneal depends on the severity of the forming operation, a given shaped part may or may not require a process anneal, depending on the method used for the forming. However, it is worth noting that it is possible to manufacture, from low-carbon steel, bolts with certain head forms with a tensile strength of 45 ton/sq. in. which may be used safely without process annealing.

Where a cold-forging operation is severe, a rimmed steel is frequently used. The outer skin of this type is very ductile because of its low carbon content, so reducing the risk of surface cracks being formed in the product. The use of this type of material is limited to carbon contents not exceeding about 0·2% carbon.

The presence of sulphur and phosphorus as impurities in the steel has an adverse effect on the ability of the steel to be cold worked. Sulphur occurs as sulphides and hence reduces the available ductility of the steel, but the effect is unimportant below 0·05%. On the other hand, high sulphur-free cutting steels (*e.g.* En 1A) are not suitable for cold forging. The nature of the steel-making process may have special advantages to offer as distinct from the straight analysis. For example, acid Bessemer steel is well known for its better machining characteristics compared with a similar composition produced by the open-hearth process.

In the case where the forging operation increases the diameter of the blank, considerable circumferential strain is involved. Wire of good surface quality must therefore be used if defects are to be avoided. The presence of seams and laps in the surface of the wire have to be avoided and special precautions (such as ingot dressing or heavy scaling during or after the rod rolling stage) are sometimes taken to provide wire of superior surface quality.

For the manufacture of components which require a higher strength than can be obtained from cold-worked low-carbon steel, a medium carbon or alloy steel is used—the required properties being obtained by heat treatment. The use of medium-carbon steels is limited to sections which can be through-hardened by oil quenching. To produce the optimum physical properties it is necessary to harden throughout the section.

In most cases cold-heading wire is prepared with a coating of lime and dry drawn using a metallic soap as a lubricant. The thickness of the coat can be controlled. For heavy extrusions particularly, a heavy lubricant coat is essential if a satisfactory die life is to be attained.

Medium-carbon and low-alloy steel wires are improved for cold forging if the intermediate wire drawing heat treatment develops a favourable spheroidized carbide microstructure. Wire with this structure will forge more easily than when a pearlitic structure is present. The final wire condition will therefore be spheroidized, annealed and bright drawn.

General steels for cold work, for example, En 2, are listed in B.S. 970; B.S. 3 111 covers materials for cold-forged, high-tensile work.

The use of cold forging is in no way limited to ferrous material. Copper, silver and certain brasses and bronzes can all be readily forged. For upsets in brass, the copper content of the brass should be at least 62% and impurities should be controlled, particularly lead and iron.

Stainless steels are well known for their higher work-hardening characteristics. Over the past few years, considerable knowledge has been gained in forging these steels and successful forging techniques have been developed for both ferritic (plain chromium) and austenitic 18/8-type stainless steels. The nickel content can be increased so as to reduce the rate of work hardening, *e.g.* En 58 E (SF 920).

Design drawing and specification

Dimensions. It is most convenient if the largest diameter of upset is used as the base line, as this upset is frequently associated with the face of the die, *i.e.* the die line.

It is of great advantage to the manufacturer if one dimension can be left ' open.' It will be seen that, with wire tolerances of 0·002 in., tool-making tolerances of 0·0005 in. and the dependence upon machine setting to achieve the final desired component shape, it is necessary to have one part of the component free from restrictions in order to accommodate any volumetric variations.

Tolerances. A graph of price plotted in relation to tolerances indicates that price rises considerably as the tolerances are reduced. In addition, it is always good practice to specify as wide tolerances as the application will permit, for the obvious reasons that tool lives are considerably increased and thus longer production runs can be obtained.

It is extremely difficult to lay down specific rules on tolerances due to factors such as material forgeability, component design and so on. However, tolerances are given in Table 1 as a guide to the possibilities of the cold-forging process.

TABLE 1 *Head, shank and length tolerances*

Nominal shank dia. (inches)	Tolerance range (inches)		
	Height	Dia. plain head	Dia. recess head*
Head tolerances:			
Up to $\frac{3}{16}$	0·008	0·010	0·012
$\frac{3}{16}$–$\frac{5}{16}$	0·009	0·012	0·018
$\frac{3}{8}$–$\frac{1}{2}$	0·010	0·015	0·025

Nominal shank dia. (inches)	Tolerance range (inches)
Shank tolerances:	
Up to $\frac{3}{16}$	0·002
$\frac{1}{4}$	0·0025
$\frac{5}{16}$ and $\frac{3}{8}$	0·003
$\frac{1}{2}$	0·0035

Length (inches)	Tolerance range (inches)
Length tolerances:	
Up to 1	0·010
1–3	0·060
3–6	0·080

*If the head form contains any form of recessing, for example, hexagon socket, material does not flow evenly to the periphery of the head form. The amount of irregularity will vary depending upon the recess and the head shape.

It is with shank tolerances that the greatest need occurs for as wide a tolerance as is possible. Obviously, the wide tolerance is the most economical to meet. In the cold-forging process, there is always a tendency for the material in the shank to forge up slightly at a position immediately under the head (due to the plastic deformation of the tool and partly to ' breathing ' of the tool assembly) and, in the case of non-extruding dies, at the extreme end of the shank where contact with the ejector is made. A closer tolerance than 0·002 in. can be held over the range, but special tooling may be required especially if the size and shape of the part is abnormal.

All tolerances should be applied according to British Standard conventions.

Concentricity. In cold forging, concentricity is understood to be the variance of one diameter to another relative to a common axis. As the punch and the die are separately mounted, the achievable concentricities are dependent on the clearances of the punch slides, the accuracy of the tool making, the accuracy of setting up and the actual design of the component.

Concentricities are best specified as total indicator readings. Acceptable T.I.R.s are in the region of about 0·005 in. at the small end of the scale and increase to about 0·020 in. for large-diameter heads and shanks.

Eccentricities. Deliberately designed eccentricities should be avoided wherever possible. It should be noted that an easy way to avoid an eccentric form is to forge a concentric shape and to trim the eccentric form in a subsequent operation. Eccentricities should be related to a centre line of the component and important features, if any, should be carefully noted.

Points. Unless a particular type of point is essential, it is convenient if the point detail is omitted. The drawing should indicate that a point is desired and thus enable the manufacturer to choose the best point form with regard to the manufacturing route.

Component application. It is of considerable benefit if essential surfaces and edges are noted. As sharp corners are not produced readily in the cold-forging process, drawings should indicate exactly where sharp corners are essential.

A knowledge of the actual application of the component materially assists the manufacture of the component.

Final considerations

Reduction in the amount of waste by forming to a shape, or to near-finished dimensions, components otherwise made from the bar, not only reduces the quantity of material converted to near worthless swarf, but also reduces the machining costs.

Ideally, if the benefits of material economy (and thus of cost reduction) are to be maximized, the designer must concern himself with some of the less obvious factors—for example, accurate stress work should be carried out to ensure that the functional needs plus the appropriate safety factor, but no more, are covered in the design and specifications. Insistence on unnecessarily fine tolerances and designing abnormal forms where standard ones are completely adequate can only result in minimizing the benefits.

Effect of carbide stringers on the distortion of die steels during heat treatment

K. SACHS, PH.D., M.SC., A.I.M.

The causes and mechanism of distortion of die steels during heat treatment, the influence of the structure of the steel and in particular the part played by carbide stringers, are studied. The author is Head of Research Metallurgy Section, G.K.N. Group Research Laboratory, Wolverhampton, and his article will be continued in future issues

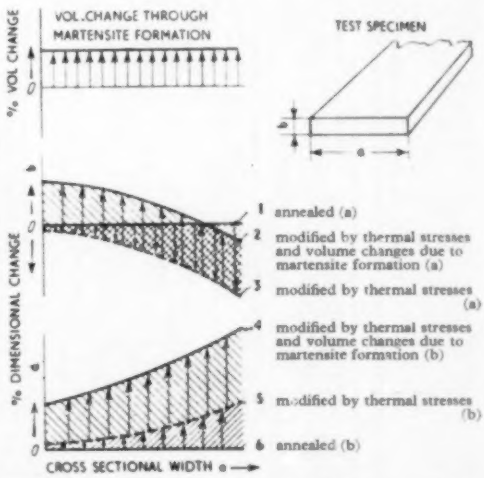
continued from last month

THE distortion of a rectangular bar, thin enough to harden right through, is illustrated schematically in fig. 15. The length of the bar is regarded as infinite, the thickness *b* before hardening is constant, and the change in width *a* is plotted on the abscissa, while the ordinate represents changes in volume and in dimensions *a* and *b* after hardening. Thermal stresses promote an approach to a spherical shape, *i.e.* decrease in width *a* and an increase in thickness *b*; the broken lines in fig. 15 show that these changes are accentuated the heavier the cross-section, *i.e.* the greater the width *a*.

The volume expansion due to martensite formation is superimposed on these dimensional changes. At low values of *a*, the expansion leads to an increase in *a* over the corresponding dimension in the annealed condition, but the wider the bar, *i.e.* the greater *a*, the more the width shrinks under thermal stresses so that the composite effect of thermal and transformation stresses is a gradual fall in the percentage increase in width. When the expansion due to martensite formation can no longer compensate the shrinkage due to thermal stresses, there will be an overall decrease in width. The thickness *b*, which increases as a result of thermal stresses, is increased even further by the volume expansion associated with martensite formation.

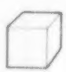
This process of dimensional change is briefly described for a number of other simple shapes, which form the basis of most tools and dies, in Table 2. Column 2 indicates the changes due to thermal stresses. Predictions of the combined effect of thermal and transformation stresses are made in columns 3 to 7, the various factors likely to influence transformation distortion being considered separately. Possible measures for increasing dimensional stability are indicated in the last column.

The combined action of thermal and transformation stresses can lead to complicated effects which are easier to explain after the event than to predict beforehand. For example, marquenching is generally believed to lower distortion (dimensional instability) as well as warping; in fact, this depends on the dimensions of the specimen. The temperature gradient is reduced and the thermal stresses are correspondingly lower in marquenching. In some cases this will diminish the compensating



15 *The combined effects of dimensional changes caused by thermal stresses (/////) and by the volume changes associated with martensite formation (\\\\\\) for samples of different width (a) and constant thickness (b); the steel is hardened throughout the thickness (b) (J. Frehser and O. Lowitzer[6])*

TABLE 2 *The dimensional changes likely to occur in hardening low or medium alloy steels of various shapes*[a]

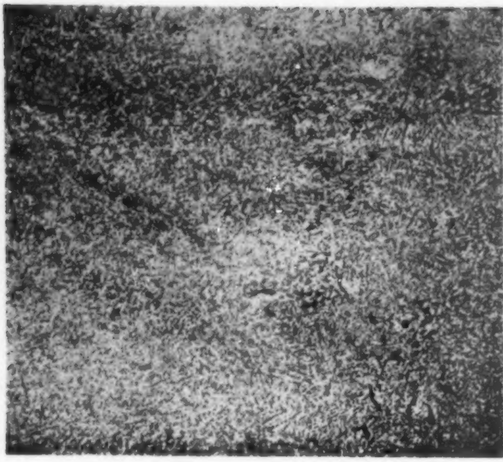
	1	2	3 to 7					8
	Shape	Influence of factors (*a*) to (*e*) on dimensional changes due solely to thermal stresses	Influence of factors 3 to 7 on dimensional changes due to thermal and transformation stresses					Measures to increase dimensional stability
			3 Hardenability	4 Hardening temperature	5 Quenching medium	6 Dimensions of specimen	7 Tempering	
A		The section increases and the effect is enhanced by: (*a*) Increase in cooling rate. (*b*) Rise in quenching temperature. (*c*) Increase in coefficient of thermal expansion. (*d*) Decrease in strength at elevated temperature. (*e*) Lowering of thermal conductivity.	The section expands to an increasing extent with progressive depth of hardening.	An increase in hardening temperatures diminishes the expansion of the cross-section if the hardenability is 'excessive'[1] and accentuates the expansion if hardenability is 'inadequate.'[1]	A decrease in cooling rate (oil, salt bath, air) is accompanied by a drop in the expansion of the cross-section.	An increase in size results in a reduction in the expansion of cross-section and length, expressed as a percentage of the original dimensions. With further increases in specimen size only the surface layers are hardened and this may even cause a reduction in length.		Against expansion of the cross-section: (*a*) The use of through-hardening steels and an increase in hardening temperature. (*b*) The use of steels of low hardenability and a decrease in hardening temperature. (*c*) Salt bath or air hardening. (*d*) Tempering as indicated in column 7. Shrinkage of cross-section does not occur.
		The length decreases with rise in thermal stresses and consequently with the changes indicated under (*a*) to (*e*).	Increasing depth of hardening counteracts the shortening caused by thermal stresses so that beyond a certain depth of hardening the length begins to increase.	The hardening temperature influences changes in length in the same way as changes in cross-section.	A decrease in cooling rate may either accentuate or diminish the increase in length.			Against increase in length: (*a*), (*b*) and (*d*) as above. Against shortening: (*a*) The use of steels of high hardenability. (*b*) To compensate for inadequate depth of hardening, an increase in hardening temperature. (*c*) Tempering as indicated in column 7.
B		The changes of dimension are equal in all directions. Flat faces belly outwards; edges become shorter (approximation to spherical shape). The effect is enhanced by a rise in thermal stresses and thus by the alterations indicated under (*a*) to (*e*) in A2.	Deep hardening increases lengthening of the edges.	A rise in hardening temperature diminishes the volume expansion and thus reduces the lengthening of the edges if the hardenability is 'excessive,'[1] but enhances lengthening of the edges if hardenability is 'inadequate.'[1]	A decrease in cooling rate reduces the increase in volume and in linear dimensions.	Increase in size leads to diminished expansion (in %).	(*a*) In low alloy oil-hardening steels tempering below 200°C. leads to shrinkage, tempering between 200°C. and 320°C. to expansion, tempering at higher temperatures to shrinkage again. (*b*) In medium alloy oil- or air-hardening steels tempering up to 500°C. causes shrinkage, between 500 and 700°C. expansion. In this context shrinkage or expansion is relative to the dimensions in the hardened condition.	Against expansion: (*a*), (*b*), (*c*) and (*d*) as under A8 (section). Against shrinkage: This does not occur.[3]
	Measurement < 400 mm.□	The area[2] diminishes with increasing thermal stresses and consequently with the alterations indicated under (*a*) to (*e*) in A2.	The depth of hardening has only an insignificant effect on the dimensional stability of the base area. Increase or decrease in area depends primarily on the factors discussed in column 6.	If the hardenability is 'excessive,'[1] a rise in hardening temperature diminishes the growth of the base area and may even cause shrinkage, but if the hardenability is 'inadequate'[1] the growth of the base area is further enhanced by an increase in hardening temperature.	A drop in cooling rate resulting from salt bath or air hardening is accompanied by reduced changes in the base area.	With increase in base area the growth in area (in %) is diminished and even shrinkage may occur. Increase in thickness of the plate, with constant base area, increases the expansion of the base area (provided the degree of through hardening and the concomitant percentage increase in volume are equal).		Against increase in base area: (*a*) For steels of high hardenability, a rise in hardening temperature and a decrease in plate thickness. (*b*) For steels of low hardenability, a lowering of hardening temperature, and an increase in plate thickness. (*c*) Salt bath or air hardening (less
C		The thickness ...	Deep hardening ...					

C		The thickness increases with rising thermal stresses and consequently with the alterations indicated under (*a*) to (*e*) in A2.	Deep hardening enhances the increase in thickness to a greater extent than does shallow hardening.	A rise in hardening temperature accentuates the increase in thickness.	A drop in cooling rate resulting from salt bath or air-hardening causes, in cases of 'excessive' hardenability,[1] increases in thickness near the lower limits of corresponding increases in thickness resulting from oil hardening. If the hardenability is 'inadequate'[1] the increases in thickness are appreciably less than in oil hardening.	Increase in thickness of the plate, with constant base area, reduces the growth in thickness (provided the degree of through-hardening and the concomitant percentage increase in volume are equal).		hardening (less effective than (*a*) and (*b*)). (*d*) Tempering as indicated in column 7. Against decrease in base area: (*a*) For steels of low hardenability, an increase of hardening temperature and a reduction in plate thickness. (*b*) For steels of high hardenability, or lowering of hardening temperature, an increase in plate thickness. (*c*) Tempering as indicated in column 7.
	Measurement < 400 mm.□	The external dimensions shrink with rising thermal stresses and consequently with the alterations indicated under (*a*) to (*e*) in A2.	Deep hardening may be accompanied by either an increase or a decrease in external dimensions, shallow hardening mostly by an increase.	If the hardenability is 'excessive'[1] an increase in hardening temperature causes a decrease in the growth of external dimensions or even a shrinkage, if the hardenability is 'inadequate'[1] there is mostly a decrease in the growth of external dimensions.	A decrease in cooling rate resulting from salt bath quenching leads to shrinkage of exterior dimensions when the hardenability is 'excessive.'[1] In cases of 'inadequate' hardenability[1] the external dimensions after salt bath hardening may be smaller, equal to, or greater than after oil hardening.	No general conclusions can be drawn.		Prediction of dimensional changes is very difficult. The rule of thumb, that the inner dimensions of rings made from steels of high hardenability remain unchanged or increase, is definitely unsound, because shrinkage may also occur. Shrinkage of the internal dimensions may be counteracted by salt bath hardening.
D		The internal dimensions change in the same way as the external dimensions.	The area may either grow or shrink because it depends on changes in both the outer dimensions and the width of metal surrounding the hole.					
		The thickness increases with rising thermal stresses and consequently with the changes indicated under (*a*) to (*e*) in A2.	With deep hardening the increase in thickness remains constant with decreasing width of metal surrounding the hole. With shallow hardening the increase in thickness is enhanced (because through-hardening is favoured by a decrease in the width of metal surrounding the hole).	As a rule, increase in hardening temperature accentuates the increase in thickness.	A drop in cooling rate resulting from salt bath or air hardening causes, in cases of 'excessive' hardenability,[1] increases in thickness near the lower limits of corresponding increases in thickness resulting from oil hardening. If the hardenability is 'inadequate'[1] the increases in thickness are appreciably less than in oil hardening.			

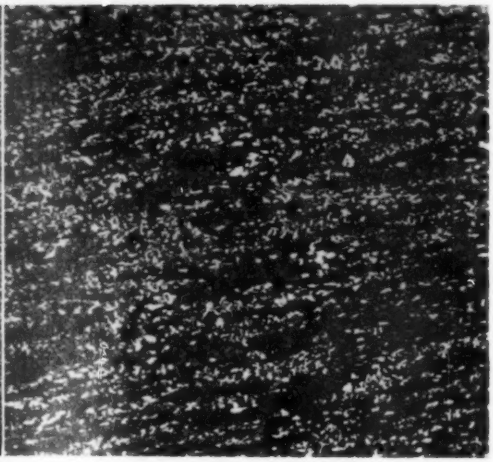
1 In this context 'excessive hardenability' means that the volume expansion on hardening is less than the maximum possible value, due to retention of austenite; 'inadequate hardenability' means that under the prevailing conditions of hardenability, cooling rate, and specimen size, a further increase in expansion, due to martensite formation, can be achieved by raising the hardening temperature.

2 Shrinkage occurs only in ledeburitic chromium steels (cf. Ref. 15).

3 Plates with fairly small holes behave like solid plates. Distances between holes vary in proportion to changes in the base area.



16 *Flow lines and dendrites in cross-section of die* $\times 1{\cdot}5$



17 *Carbide distribution near surface of die* $\times 90$

effect which longitudinal contraction under thermal stresses exercises on the expansion on hardening, so that the increase in length may be greater after marquenching than after oil hardening.

Distortion due to directional differences in expansion characteristics

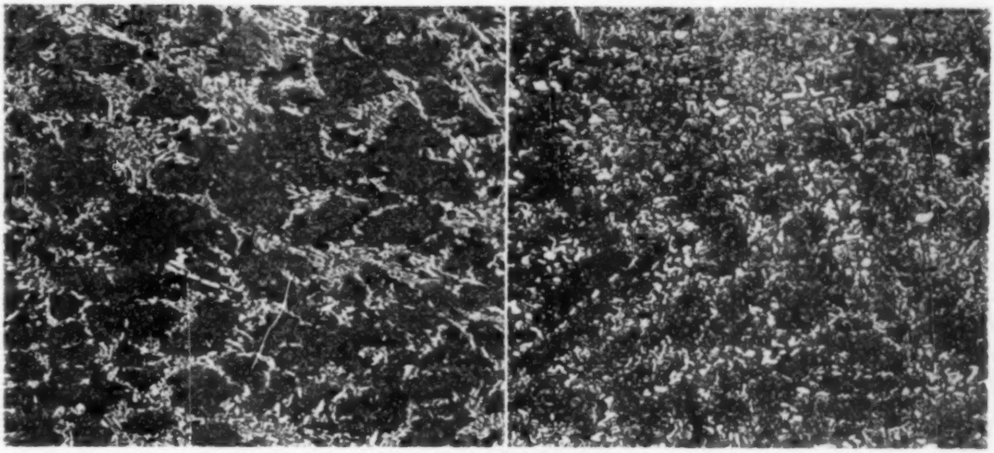
A distinction has been drawn between changes in volume and distortion; this distinction implies that distortion involves dimensional changes which are not proportional to overall volume changes. It is also possible to distinguish between distortion, as defined above, and warping, which implies some loss of symmetry and bending or twisting. It has been shown in the previous section that dimensional changes will be different in various directions, *i.e.* distortion will occur, as a result of thermal stresses alone, even if the material behaves isotropically. It has been demonstrated, however, that tool and die steels with directional alignment of carbide particles (stringers) are far from isotropic.

A practical illustration of this effect is the distortion of a ring die (7 in. i.d., $10\frac{1}{4}$ in. o.d.) in a 2% C, 12% Cr steel. This was found to be due to—or was at least attributed to—differences in the alignment of dendrites and the directionality of the carbides between the surface and centre of the cross-section. The macro-structure is shown in fig. 16.

Coarse dendrites are clearly visible. In the centre of the section they are oriented in all directions, but within about $\frac{3}{8}$–$\frac{1}{2}$ in. of the surface they tend to be parallel to the latter and those dendrites which remain normal to the surface are short and broken up. The ring was machined from a round slab which had been upset by hammer-forging, and the effect of the hot forging had evidently not penetrated very far into the metal. The difference between the surface layers and the centre is shown up very clearly by the distribution of the carbides. Fig. 17 illustrates the carbides near the surface in the cross-section, figs. 18 (*a*) and (*b*) those in the centre in both transverse and circumferential sections. It is evident that the carbides in the surface layer have been broken up and forced into the direction of flow of the metal, while those in the centre have, in large measure, retained their dendritic arrangement.

The surfaces of the cross-section corresponding to the external and internal diameters of the die were examined on a contour microscope, and the results are plotted in fig. 19. The points on the external diameter show scatter, due to experimental error and roughness of the surface, but there is no evidence of distortion. In the bore, on the other hand, there is a definite bulge near the middle of the section. It appears that there is a difference in dimensional response to heat treatment between material which has been heavily worked and material in zones which have remained relatively unaffected by hammer forging. The external diameter was hammer forged in the early stages of manufacture of the billet. The flat surfaces were forged when the billet was upset, and it can be seen in figs. 16 and 19 that the hammer had more effect than the anvil on the structure.

The bore was machined or trepanned out, so that only the surface zones, corresponding to the upset faces, were hot-worked, and there was a large portion in the centre retaining its coarse,



18 *Carbide distribution near centre of die* ×90

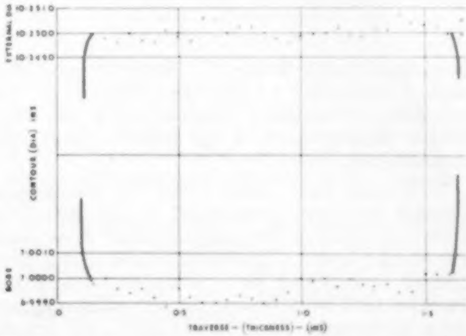
equiaxed dendritic structure; the differential dimensional changes of the surface layers along the bore are presumably responsible for the bulge in the contour. It can be assumed that the equiaxed material will show a slight isotropic expansion as a result of heat treatment, while the hammer-forged zones will expand in the direction of the flow-lines and carbide stringers and contract at right angles; this would yield radial expansion and circumferential contraction, resulting in severe internal stresses leading to distortion which cannot easily be predicted, but which in this case produced unbalanced circumferential contraction, throwing the die out of round.

An account of the mechanism of this anisotropy due to carbide stringers has been given by Frehser,[15] based on extensive and detailed experiments. The effect of carbide directionality was studied by measuring the change in length on hardening of cylindrical specimens cut in different direction from cast ingots and forged bars. In cast ingots, the specimens showed longitudinal contraction and transverse expansion, in direct contrast to the effects observed in forged bars; solidification of the ingot had formed large columnar crystals with radial orientation of carbide lines. Thus, in cast ingots as in forged bars, expansion occurs parallel to the carbides, contraction at right angles to the stringers. Forging draws the carbides out in the direction of the longitudinal axis of the bar, and the longitudinal expansion and lateral contraction are accentuated by increasing deformation. This is exemplified in Table 3, giving experimental results selected from the much more detailed tables in Frehser's paper.[15]

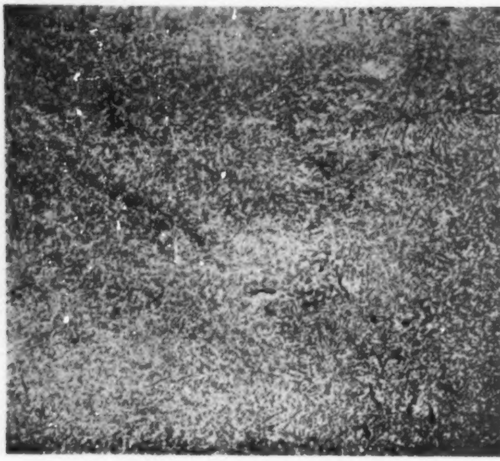
TABLE 3 *Dimensional changes in cast and forged specimens oil-hardened from 950°C.*

Forging Deformation %	Dimensional change in %	
	Longitudinal	Transverse
As cast	−0·081	+0·028
75·8 (core)	+0·17	+0·03
75·8 (surface)	+0·11	+0·01
87·5 (core)	+0·19	—
87·5 (surface)	+0·13	—
96·9 (core)	+0·14	—
96·9 (surface)	+0·13	—

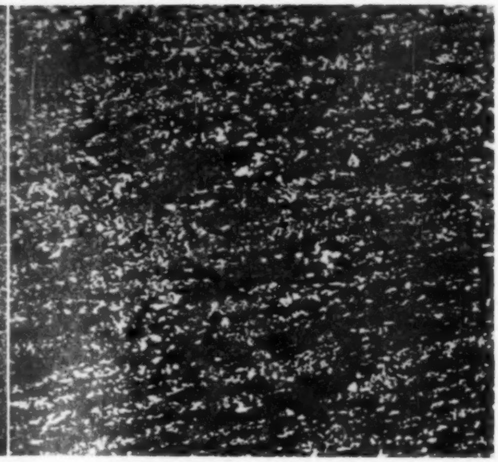
The effect of forging is summarized in fig. 20, where longitudinal and transverse dilatations are plotted against the percentage deformation. The directional effect and its intensification with heavier forging is shown in the dimensional changes of



19 *Contour microscope survey of external diameter and bore of die*



16 *Flow lines and dendrites in cross-section of die* ×1·5



17 *Carbide distribution near surface of die* ×90

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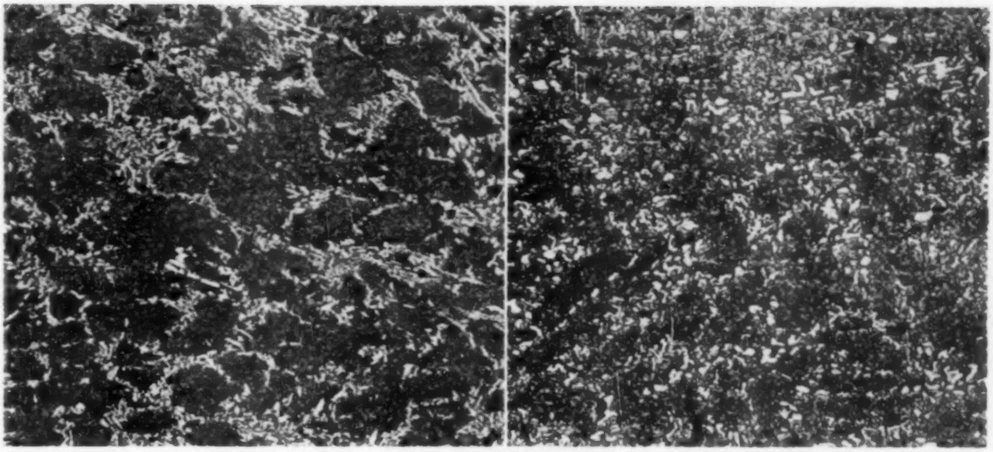


18 *Carbide distribution near centre of die* ×90

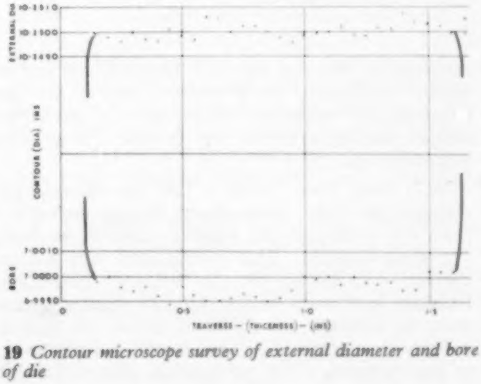
equiaxed dendritic structure; the differential dimensional changes of the surface layers along the bore are presumably responsible for the bulge in the contour. It can be assumed that the equiaxed material will show a slight isotropic expansion as a result of heat treatment, while the hammer-forged zones will expand in the direction of the flow-lines and carbide stringers and contract at right angles; this would yield radial expansion and circumferential contraction, resulting in severe internal stresses leading to distortion which cannot easily be predicted, but which in this case produced unbalanced circumferential contraction, throwing the die out of round.

An account of the mechanism of this anisotropy due to carbide stringers has been given by Frehser,[15] based on extensive and detailed experiments. The effect of carbide directionality was studied by measuring the change in length on hardening of cylindrical specimens cut in different direction from cast ingots and forged bars. In cast ingots, the specimens showed longitudinal contraction and transverse expansion, in direct contrast to the effects observed in forged bars; solidification of the ingot had formed large columnar crystals with radial orientation of carbide lines. Thus, in cast ingots as in forged bars, expansion occurs parallel to the carbides, contraction at right angles to the stringers. Forging draws the carbides out in the direction of the longitudinal axis of the bar, and the longitudinal expansion and lateral contraction are accentuated by increasing deformation. This is exemplified in Table 3, giving experimental results selected from the much more detailed tables in Frehser's paper.[15]

TABLE 3 *Dimensional changes in cast and forged specimens oil-hardened from 950°C.*

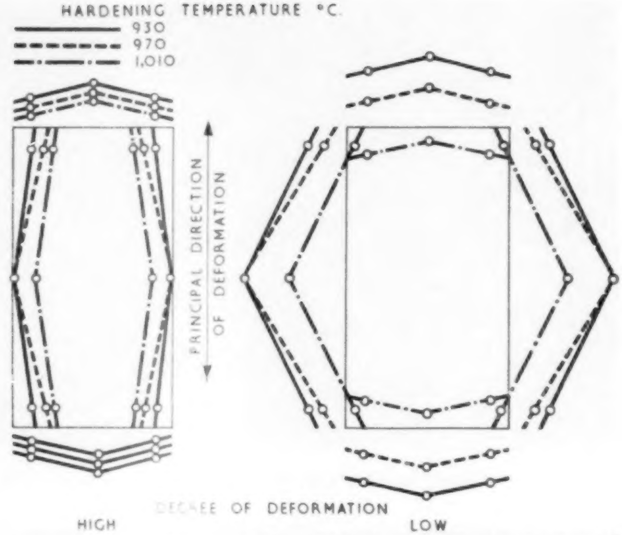
Forging Deformation %	Dimensional change in %	
	Longitudinal	Transverse
As cast	−0·081	+0·028
75·8 (core)	+0·17	+0·03
75·8 (surface)	+0·11	+0·01
87·5 (core)	+0·19	—
87·5 (surface)	+0·13	—
96·9 (core)	+0·14	—
96·9 (surface)	+0·13	—

The effect of forging is summarized in fig. 20, where longitudinal and transverse dilatations are plotted against the percentage deformation. The directional effect and its intensification with heavier forging is shown in the dimensional changes of

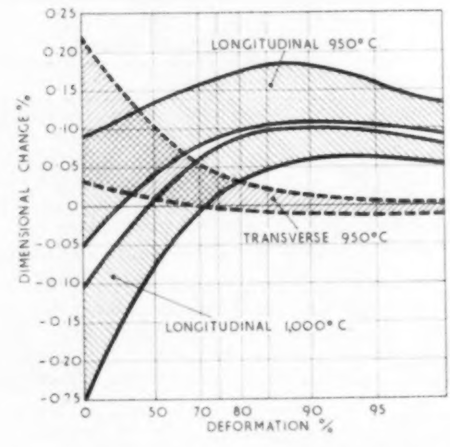


19 *Contour microscope survey of external diameter and bore of die*

21 RIGHT *Influence of deformation on overall dimensional changes in oil hardening (schematic) (J. Frehser[15])*



20 BELOW *Influence of deformation on dimensional changes in different directions in hardening a high-carbon, high-chromium steel (J. Frehser[15])*



rectangular plates in fig. 21. Expansion is less at higher hardening temperatures, owing to the retention of increasing proportions of austenite. Heavy forging converts the lateral change into a contraction.

It is seen from Table 3 that the dimensional changes are more pronounced in specimens cut from the centre of the forgings than those from the surface layers. This is associated with a finer carbide distribution at the surface, where the carbides have been broken up into smaller aggregates by forging. As indicated above, the general anisotropy is attributed to the directional alignment of the carbides. The explanation offered for this influence of the carbides is the difference in thermal expansion characteristics between the carbides and the matrix.

to be continued

New gas exhibit at the Building Centre

The Gas Council's permanent exhibition at the Building Centre, Store Street, London, W.C.1, has been completely redesigned and is intended to be of interest to architects, builders, public authorities and members of the public. The new section was officially opened recently by Sir Basil Spence, R.A., R.D.I., P.P., R.I.B.A., Sir Henry Jones, M.B.E., chairman of the Gas Council, and Sir Alfred Hurst, K.B.E., C.B., were also present and gave short addresses.

A special feature of the exhibition is a section devoted to house heating by gas, in which examples of small-bore central heating and warmed-air heating installations are shown. Other features include a display of modern gas domestic appliances—cookers, water heaters, refrigerators, home laundry equipment, convector room heaters and coke-fired heaters and boilers.

Coating helps cold extrusion of titanium

Titanium metal coated with a fluoride-phosphate coating and lubricated with a solid film lubricant has successfully been cold extruded into wire and tubing by A. M. Sabroff and P. D. Frost, of Battelle Memorial Institute's Light Metals Division, Ohio, U.S.A.

Though cold extrusion is widely used in the forming of steel and certain other metals, the process has been applied little, if at all, in the production of titanium products, according to Sabroff and Frost. They say fabrication of titanium by cold extrusion has probably been retarded most by the inability to achieve a satisfactory surface finish on the metal.

The new coating imparts a good surface finish to the metal and acts as a lubricant retainer. It is applied by immersing titanium in a fluoride-phosphate bath operated at room temperature. The solid film lubricant used in the extrusion technique is a self-drying, gum-resin mixture containing graphite and molybdenum disulphide.

Practical and economic problems of machining cavities by spark-erosion

W. ULLMANN, Dipl.-Eng. E.T.H., Locarno, and T. G. TRAUBE, Dipl.-Ing. E.T.H., Locarno

During recent years, the practice of machining moulds and dies by the spark-erosion method has come more and more to the fore. Some of the requirements which have had to be met to make the development of this method possible are summarized and the economic factors discussed. The authors are both with the Agie Co., Locarno, Switzerland—thanks are due to the company for their courtesy in providing photographs. Agie Co. is represented in the U.K. by Vaughan Associates Ltd., 4 Queen Street, London, W.1

THE MACHINING of perforations and cavities was originally the main field of application for spark-erosive machine tools. This method was adopted either because, for some reason, the form was complicated to machine, or because difficulties arose due to the actual material itself. Alterations in the metallurgical structure of hardened cutting dies and similar tools are part of the latter problem. Dependent on the quality of the spark-erosive machine tool employed for the purpose, operations of this kind may, or may not, result in the production of tools which can be considered ready for practical use; if they are made on machines which are not up to the highest technical standards, it may become necessary to allow for a subsequent finish-machining operation.

However, during recent years, the practice of machining moulds and dies by the spark-erosion method has come more and more to the fore. In the near future, probably as many machines will be engaged in the machining of dies and moulds as in all other fields of application put together. This development has only been possible due to the fulfilment of certain specific requirements which can be summarized as follows without any claim being made that the list is complete:

1. *Adequate erosion rates* on machines utilized for the production of large-size dies.

Under this heading it can be stated that for about the past two years a race has been in progress between some manufacturers with the object of being able to claim the highest possible erosion rates for their machines. These very high erosion rates should be accepted with caution, because: (*a*) In certain circumstances, very high erosion rates can cause such far-reaching metallurgical and structural changes, or at the very least lead to such high surface-roughness values, that the times required for finishing are increased to an extent which renders any gain due to shorter roughing times illusory.

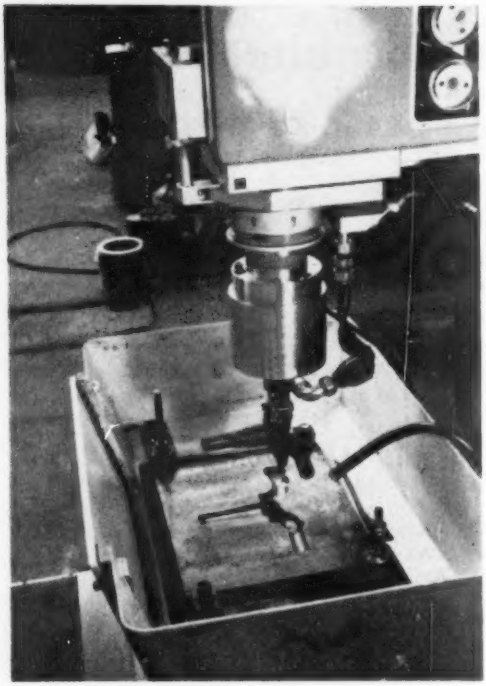
(*b*) High erosion rates cease to be practicable if the machine applied for the job does not have the requisite stability. This question will be dealt with later. However, in this respect the user of spark-erosion machine tools can fall into the same errors as, for example, a manufacturer who makes use of carbide cutting tools on unsuitable machines, with the result that these have an even shorter life than steel tools.

2. Even greater care should be devoted to a *low electrode wear* than to the erosion rate. The actual saving in electrode material is perhaps of minor importance, although this does frequently also play a part; what is more important, however, is that: (*a*) changing the electrodes too often increases the proportion of idle time, and it is in paid working hours in particular that savings are to be achieved, thanks to spark-erosion machine tools; and (*b*) an excessive wear on the electrodes, even when considerable numbers of them are utilized, will give rise to difficulties when machining precision dies, finely engraved forms, and forms with sharp edges.

3. The latter problems in particular have recently brought a further aspect to the forefront: *the possibility of varying the spark gap* and of working with a small gap. For a first approximation, the following equation applies:

$$L_s = f\,(M^2_1, V, \ldots),$$

i.e., the length of the spark L_s is influenced by



1 *Oscillating head for Agietron machine tool*

the pairing of cathode and anode material (workpiece and electrode material) that is, in practical jobs given fixed parameters, and the working voltage V. Additional parameters have only a secondary influence.

On the other hand, the formula

$$\text{Erosion rate} = f\,(V\ldots),$$

applies, which means that the erosion rate is also a function of the working voltage V.

When designing the generator, there is then the problem of achieving effective erosion values for finishing, with a low working voltage. The rest is then a question of operational technique, that is the selection of roughing and finishing settings when working and the appropriate undersize of the electrodes.

Now this, in turn, presupposes that:

4. There are adequate *facilities for fine adjustment* on the spark-erosive machine tools. The main parameters (I, U and C) must, therefore, be capable of individual adjustment and widely variable.

5. A *fine control* for the feed is, of course, an essential prerequisite. This is especially important when complicated dies without perforation (trepanning) are to be machined with correspondingly unfavourable flushing conditions, as otherwise the resultant down times are far too high. The problem is not solved by the fine control alone, however:

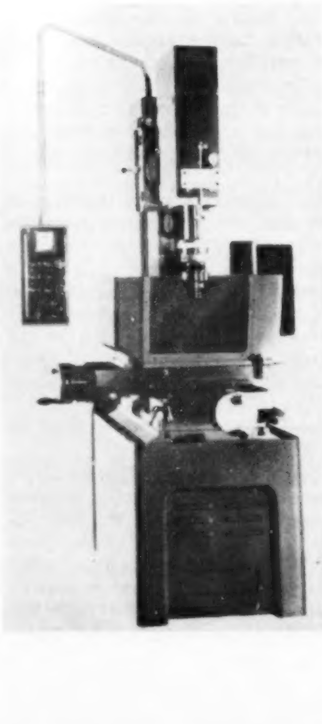
6. As *the flushing* must be supported by mechanical means: (*a*) This can best be achieved by suitable oscillating heads (fig. 1), the design of which is most exacting. They must not be sensitive to variation in the weight of the electrode when dissimilar jobs are being machined, must offer the best possible facilities for chucking and ensure that the alignment is absolutely true.

(*b*) Attachments which bring about a withdrawal of the electrode at constant time intervals cannot replace the high-frequency pumping and suction of oscillating heads. With the former, optimum conditions in the spark gap prevail during all too short a fraction of the effective operating time.

(*c*) However, flushing in the gap can be carried out to advantage through the electrode or horizontally by means of jets, depending on the problem to be overcome.

(*d*) However, these expedients have a practical value only if the work is carried out with adequate quantities of *dilute dielectric fluid*.

7. As has already been mentioned, one of the most important problems in the machining of dies and moulds is probably *the rigidity and precision of the actual machine tool itself*. There are many jobs



2 *Agietron machine tool BL 6*

in drop-forging establishments for which the maintenance of close tolerances is not demanded, but, despite this, the constructional rigidity of the machine is of vital importance. Experience has shown that two machines which can be applied to advantage in drop-forging plants are the AGIETRON BL 6 machine tool (fig. 2), and the AGIETRON BQ 12 machine tool (fig. 3).

The more important technical data of these machines are given in Tables 1 and 2.

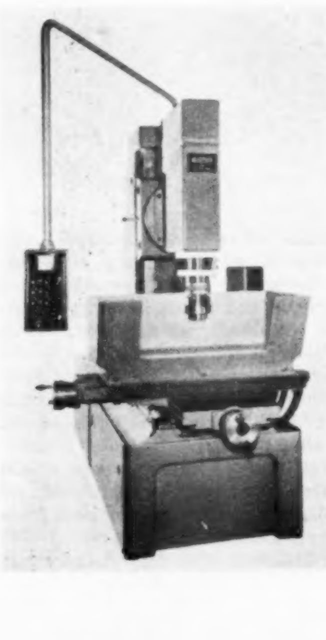
TABLE 1 AGIETRON *type* BQ 12

Machine tool	Inches
Height	117
Width	44
Depth	96
Clamping surface	17 × 44
Slide movement	19·5 × 27·5
Universal bore head:	
Way of coarse adjustment ..	16·5
Automatic movement of quill ..	14
Total vertical movement ..	30·5
Net weight	approx. 4 t.
Generator:	
Maximum power input	approx. 12 kW.

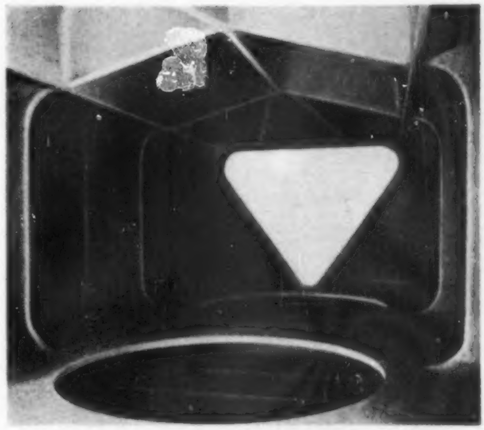
Stock removal and surface quality:

Maximum stock removal: Cu/steel more than ·12 cu. in. = 2 cm.^{3}/min. (7·2 cu. in./h.), wear of electrode less than 10%

Best surface quality obtained: 12 μin. (r.m.s.)



3 *Agietron machine tool BQ 12*



4 *Machine base, inside view showing ribbed cast iron structure*

TABLE 2 AGIETRON *type* BL 6

Machine tool	Inches
Height	104
Width	32
Depth	82
Clamping surface	13·5 × 23·5
Slide movement	19 × 15
Universal bore head:	
Way of coarse adjustment ..	10
Automatic movement of quill ..	9·5
Total vertical movement ..	19·5
Net weight	approx. 2·5 t.
Generator:	
Maximum power input	approx. 6 kW.

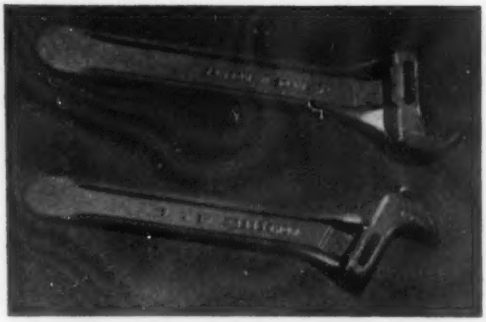
Stock removal and surface quality:

Maximum stock removal: Cu/steel more than ·06 cu. in. = 1,000 mm.^{3}/min. (3·6 cu. in./h.), correspondent wear of electrode less than 10%

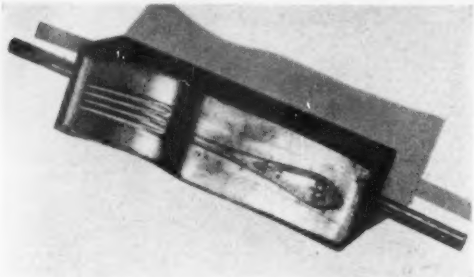
Best surface obtained: 12 μin. (r.m.s.)

These machines are constructed and handed over for acceptance with tolerances similar to those of jig-borers. The beds (fig. 4) and columns of the machines are of heavy, ribbed cast iron, with all stresses removed: the design of these machines is, therefore, similar to that of high-precision column-type boring machines for conventional machining. This may seem paradoxical in view of the fact that no actual machining forces are exerted during spark-erosion, but it has nevertheless proved essential for the following reasons:

(*a*) During roughing, erosion rates can be applied which may be as much as the second or third power of the finishing rates. As is known, it is generally necessary for erosion to be carried out with more than one electrode. Now, if a slight inaccuracy in



5 *Forging die for adjustable spanner, high-temperature steel*



6 *Die for silver-ware, die steel*

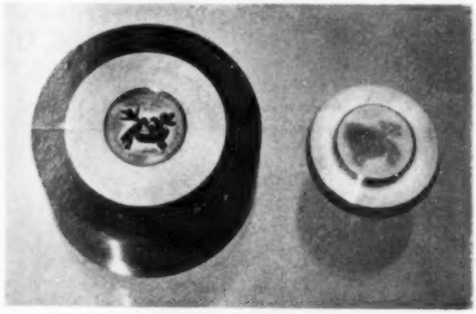
positioning should occur when changing the electrodes, even if this is only in the order of 0·01 mm., which in itself is a very small displacement, it may under certain circumstances entail the additional erosion of thousands of cubic millimetres when finishing, thus causing the total machining time to rise enormously.

(*b*) Although no machining forces occur, the electrical discharges are known to be accompanied by powerful waves, which are of high frequency (corresponding to the spark frequency) and which can under certain conditions cause not only the electrode to vibrate, but the whole body of the machine as well. The former is particularly troublesome when machining relatively flat forms with at least one major dimension, as, for example, in the following specimens (figs. 5 and 6).

With forms of this type there is some danger of electrode flutter, although the risk of this occurring is reduced for compact forms as in fig. 7: even so, the entire system machine-electrode-workpiece may be set in vibration. The effects of both eventualities, electrode flutter and vibrations in the entire system must be clearly understood.

The primary requirement for economic operation

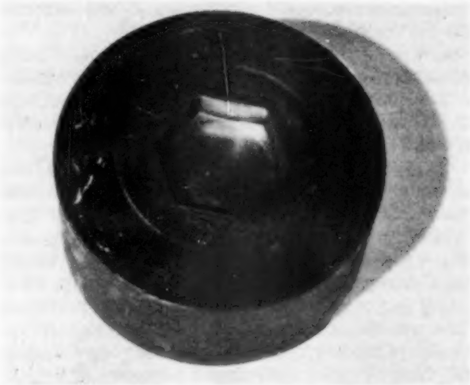
7 *Forging die for car parts, high-temperature steel*



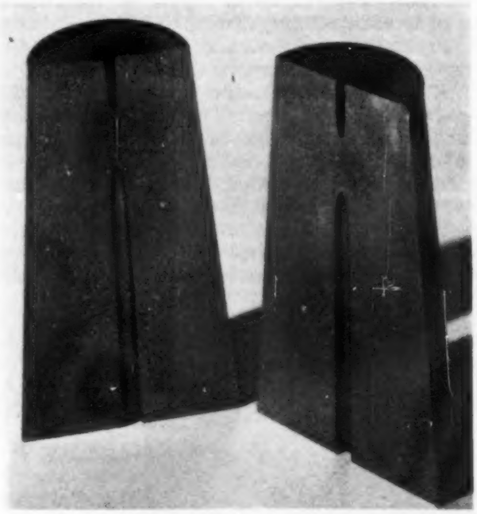
8 *Extruding die for aluminium tubes, hardened steel*

is the maintenance of an optimum spark gap. Flutter and vibration will continually alter this distance which, according to the operating level selected, is of the order of less 1/10 (roughing) up to less 1/100 mm. (finishing), so that the correct erosion merely takes place during a fraction of the time. It is also known that selected operating levels only become applicable and efficient when a critical electrode surface is exceeded and is in operation, that is to say, in shop parlance, when it is 'loaded.' When flutter or vibration occur, only part of the electrode surface will be 'loaded,' so that at the best energy is lost and at the worst no erosion takes place at all.

Unfavourable conditions such as this can result



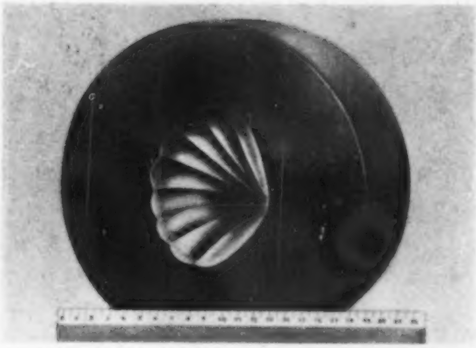
9 *Heading die, hardened steel*



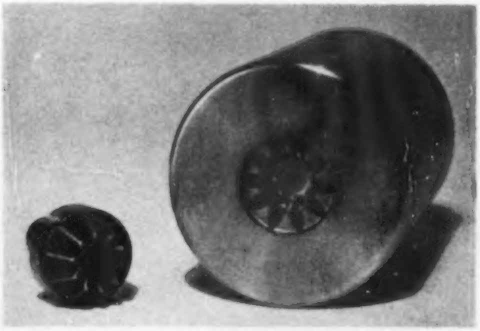
10 *Die for nails, hardened steel or tungsten carbide*

in the normal machining times being multiplied considerably. Only the design of the machine offers any safeguard against this. Even the best chucking and electrode-holding attachments alone are of little use.

Assuming that all these conditions are fulfilled, it can be stated that almost any die can be flawlessly machined from a technical point of view. It is known that spark-erosion machine tools designed in the light of present-day technical requirements do



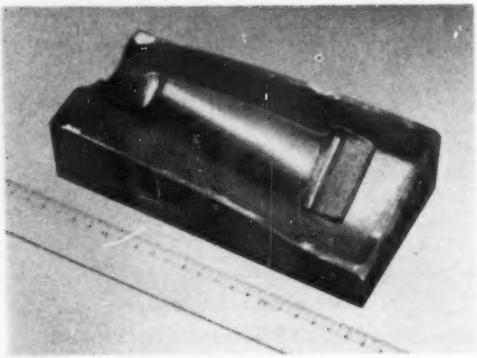
11 *Mould for alarm-clock housing, hardened steel*



12 *Plastic mould for bevel gear*

achieve sufficiently good surface qualities. In any event, an adequately small depth of roughness can be attained, whereby in certain cases a brief re-polishing may be required merely for appearances' sake: not in the sense of smoothing, but rather with the object of achieving a gloss or an easily obtainable modification of the surface structure. This only becomes necessary when glossy components are to be produced by means of glossy moulds.

This merely leaves the economic side of the problem to be investigated. With the exception of border-line cases (fig. 8) where work can be carried out with a single electrode, several electrodes are required for machining dies. Leaving aside the most simple problems to be examined, conventional methods being reserved for these anyhow, the point at issue is an economic investigation of testing the possibilities of an economic electrode production which will be simplified by means of the following classification:



13 *Forging die for turbine blades, high-temperature steel*

14 *Press mould for glass*

Economic electrode production

1. *There are some forging dies which are so straightforward that the procurement of electrode material presents no difficulties.*

Two typical examples (figs. 9 and 10) show that in cases such as these, round or profile material available from stock or in ordinary commercial use is normally employed, which either requires no additional machining at all, or merely simple pointing and turning of the phase. If higher demands for accuracy are stipulated, this material can be machined with the greatest ease.

Copper is the material usually employed, it being possible to re-machine this or utilize it for smaller dimensions, so that the procurement of electrodes can almost be ignored when making cost calculations.

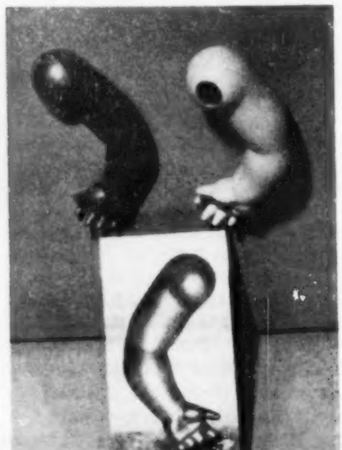
2. *Certain forging dies are so complicated that one-off production of electrodes is without doubt justifiable from an economic point of view.* Two typical examples (figs. 11 and 12) illustrate this. Fig. 11 shows a tool on which for optical reasons high demands are made in respect of sharp, clean edges and evenness of the through-shaped surfaces. The use of conventional methods offers an opportunity of milling the work, involving very lengthy finishing by hand, without any assurance of a clean-cut appearance. Machining even several (three) convex shapes in copper offers unmistakable advantage.

The example illustrated in fig. 12 hardly requires comment. It is incomparably more economical to machine three pinions in copper on the outside than to produce the negative mould of a taper pinion.

Practical examples such as these are, moreover, particularly common among moulds for plastics.

3. *When a master mould is in existence from which electrodes can be produced.* This was by far the most common occurrence and of particular importance in drop forging and hot pressing shops, and is adopted for: (*a*) the production of spares, and (*b*) reconditioning worn dies.

Both are becoming more and more widely used in industry, the importance of the reconditioning which can be effected on hardened dies having not



15 *Mould for doll arm*

UPPER RIGHT, *Celluloid model*

UPPER LEFT, *Cast electrode*

BELOW, *Mould*

become generally accepted until recent years. More and more drop-forging works are adopting the practice of leaving a die in operation for fewer blows than previously, before the damage becomes too great and cracks penetrate too deeply, and reconditioning it relatively quickly by erosion. The total yield from a die block can be increased considerably in this manner. Easily machined burred surfaces are ground, complicated offset ones can as well be reconditioned by erosion, which may necessitate the application of a special technique in which the entire surface is roughed with large-size electrodes, whereas the actual engraving is, however, finish-machined with chamfered electrodes.

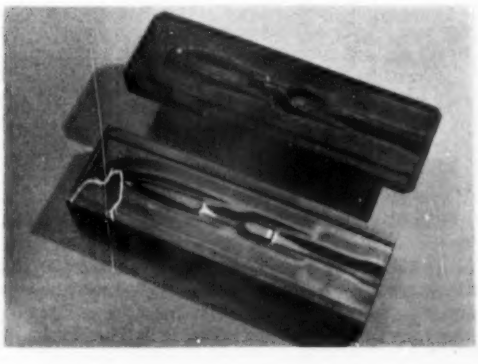
The technique of electrode production is important and the special skill required must be acquired. These problems can today be regarded as solved if the correct method is selected and the works are willing to take the trouble to learn the tricks of shop production. The following methods may be utilized:

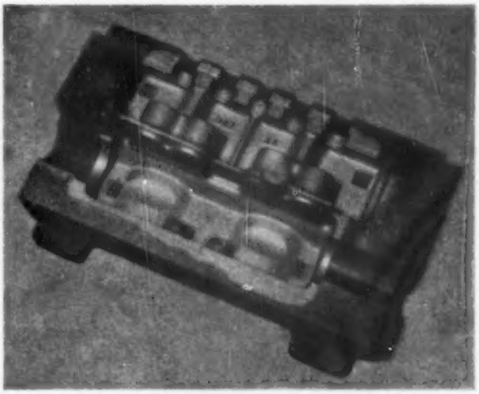
(*a*) *Electrode forging* usually out of electrolytic copper. In this method the shrinkage can today be controlled to such an extent that even tools for precision forging (see fig. 13) can be flawlessly machined. Thus the easier problems present no difficulties.

(*b*) *Electrode extrusion*, assuming that the works in question—a drop forge for instance—has suitable presses at its disposal. If this is the case, extrusion is a preferable method to forging, particularly when the engravings are complicated, sharply angled and stepped, when the volumes within the engraving are distributed unevenly, or in cases where engravings occur mainly on the vertical walls of the die.

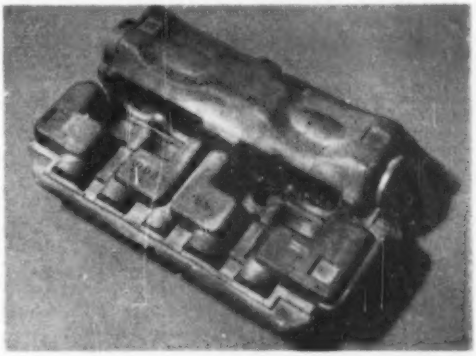
Fig. 14 illustrates a typical instance in which extrusion is a superior method to forging, and in which extrusion has been carried out with a centre arbor so as to obtain a good radial displacement of the material.

16 *Forging die for pliers*





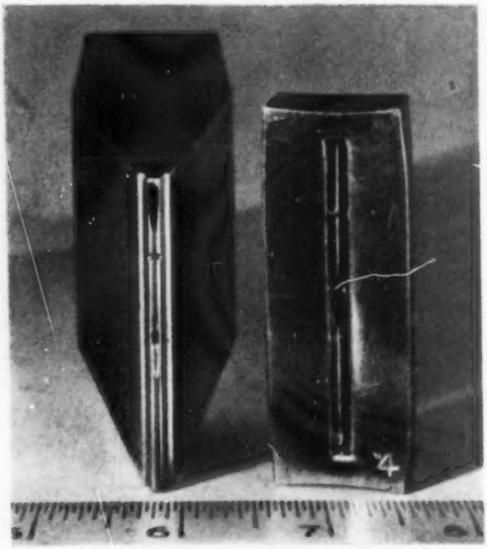
17a *Casting die for motor housing*



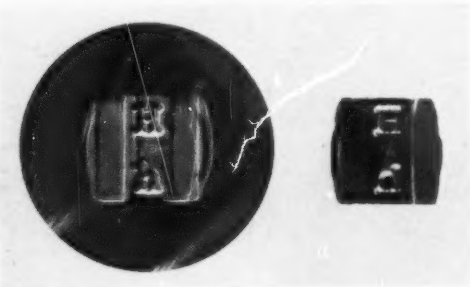
17b *Copper electrode manufactured by metal-spraying process*

(*c*) *Electrode casting* in gunmetal is only to be recommended for less-accurate forms, in which eventually cast electrodes serve for the roughing processes and finishing is carried out with an electrode of better quality. Fig. 15 illustrates a typical case in which this method is adequate.

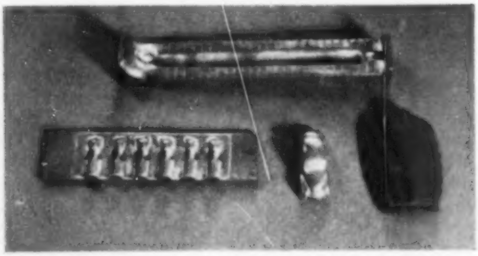
(*d*) *Metal-sprayed electrodes* (today, most recommended for drop forging dies and moulds) in the past had not been very homogeneous, so that they gave a low degree of accuracy and surfaces of average quality with extremely high wear. The development of this method has been a quick one during these last times. New, improved injection plants have been developed, with the result that sprayed electrodes may be used with practically the same or better result than forged and extruded ones. They can be obtained spraying into a cavity or starting from a positive model, thus opening new



18 *Punch for needle die, hardened steel or tungsten carbide*

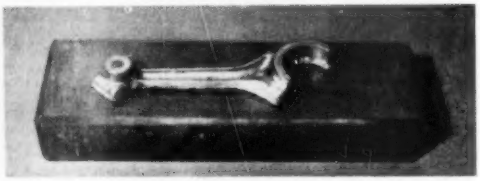


19 *Die for typewriter characters, tungsten carbide*

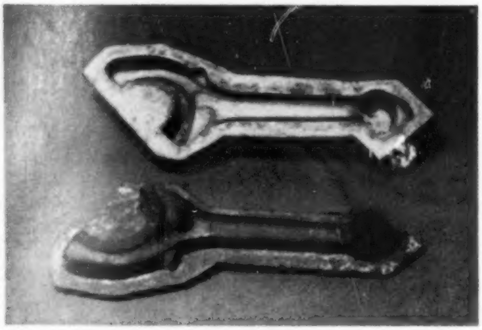


20 *Electrodes made by electroforming.* TOP, *Holder for ballpen.* BELOW, LEFT TO RIGHT, *Plastic teeth, toy car, perfume bottle*

21 *Die for pressure casting for furniture mounting.* LEFT TO RIGHT, *Model, plasticform, electrodes die finished by spark-erosion*



22a *Model for connection rod*



22b *Female die and metal-sprayed electrode*

fields of application for spark erosion (figs. 16 and 17).

(*e*) *Form sintered electrodes.* Outstanding results are achieved with these. For the time being, however, their application should be restricted to works in possession of suitable plant and experience.

According to circumstances all these electrodes may be undersize, that is to say, either etched down or filed, or not. The increased size of the die by amount of spark gap is practically always well within the permissible tolerances. Should this not be the case, this will necessitate the

4. *Production of electrodes in a specially machined master die.*

This procedure must, for example, be adopted for the production of high-precision tools for the needle industry (fig. 18) and—unless other methods are chosen—for the production to tools for typewriter

components (fig. 19). Although not necessarily for reasons of accuracy, this method can frequently be recommended for multiple moulds as well.

The following problem represents a special case:

5. *Production of electrodes commencing from a pattern*, when the one-off production of the electrodes has to be discarded for economic reasons, and no initial or master mould is available. In this case, excellent results have been obtained with the galvano-plastic method (electroforming). Fig. 20 illustrates a number of accurate, rigid electroformed electrodes which have good surfaces.

An idea of the process can be obtained from fig. 21. A plastic mould is made from a pattern in a suitable shrink-resisting, cold-straining material, which produces surfaces having a smoothness comparable to glass. The latter are made conductive with graphite or special lacquers and the castings (that is concave moulds) are placed in the copper bath. By this process electrodes with a wall thickness of up to 8 mm. can be produced.

Metal spraying enables industries with bigger dies and moulds to follow a similar, very economic pattern. It is not only possible to spray copper electrodes into a master. A technique has been developed to start from a positive master (model of the piece in wood, plaster, plastic or metal) over which a provisional mould of zinc is sprayed. The zinc moulds are used for the spraying of copper electrodes (fig. 22).

The combination of these techniques with the electro-erosion machining of dies represents a revolution in the manufacture of dies and moulds, a die ready for use being produced direct from the pattern by means of a galvanizing plant or metal spraying and by spark-erosion machines which operate automatically except for the changing of electrodes, without the services of a diemaker being required.

One should, however, not permit oneself to be led astray by this apparently effortless process. A command of the operational technique and ' know-how ' remain essential prerequisites. An analysis must be made of the applications of this interesting method from technical and economic aspects of machining dies. When electrodes are produced, consideration must be given to the selection of electrode material, methods of production and checking, which must facilitate the exchange of accurately adjusted electrodes; and the appropriate equipment—usually simple—must be available. Then there remain the actual problems of how to operate with the machine—the determination of electrode undersize and the selection of steps.

The know-how—the operating technique—is, therefore, concentrated on preliminary preparation for the job—a not uncommon trend of the day. The time of high-grade technical staff need, however, no longer be dissipated in hours of machining work and finishing by hand if the conditions of which mention has been made initially are fulfilled. A suitable spark-erosive machine tool then offers the perfect solution from a technical and economic point of view for a large number of operating problems.

Steel for sub-zero temperatures

' Operation Cryogenics ' was the name given to a full-scale test of a new alloy steel developed by the International Nickel Co. Inc. for the storage and handling of liquids at very low temperatures.

It is known that many steels, although tough and strong at room temperatures, become excessively brittle when cooled to sub-zero temperatures. It is also known that the presence of nickel greatly improves the toughness of steels down to temperatures as low as −200°C.

The rapid increase in the use of liquefied gases like oxygen, nitrogen and methane, involving service temperatures of the order of −200°C., has quickly focused attention upon the need for materials for handling them with safety and economy.

The newly developed 9% Ni alloy steel has passed all the laboratory tests but, as a practical demonstration of its suitability, three companies joined in organizing a full-scale experiment which involved:

(1) Subjecting a welded rectangular tank, similar in design to those that would be used to transport methane in sea going tankers, to repeated blows, up to and slightly exceeding 80,000 ft. lb., from a 2-ton steel ball. In this test, liquid nitrogen was pumped into the tank to cool it to −196°C.

(2) Subjecting a 4 by 13 ft. cylindrical tank, similar in design to one which would be used for land-based storage or transportation of liquid gases, to a pressure several times greater than its designed strength and then pressurizing to failure to enable the type of fracture to be examined.

The three co-operating companies were the International Nickel Co. Inc., the Chicago Bridge & Iron Co. and the United States Steel Corporation, all of whom see a big potential market for 9% nickel steel. Tonnage oxygen plants are being installed in increasing numbers near steelworks and other industrial plants and there is a promising market underlying the liquefaction and sale of some of the billions of cubic feet of methane flared-off and wasted at oil and petroleum fields throughout the world. The volume of this gas when liquefied at −157°C. is reduced by 600 times and transportation in special tankers for very long distances, for example, U.S.A. to Europe, becomes an attractive proposition. The economics of the liquid gas market demand that the tankers must be built from a safe and relatively low-cost material which is commercially available and readily welded.

A/B Nyström & Matthey

Johnson, Matthey & Co. Ltd. have acquired a controlling interest in the Swedish precious-metal company A/B Gösta Nyström of Stockholm. Mr. Gösta Nyström, who founded the business in 1917, has retired and a new board has been appointed consisting of four Swedish and two British directors, with Mr. Ove Trulsson as chairman.

A/B Gösta Nyström supply precious-metal products for all industrial purposes as well as for jewellery, silversmithing and dental requirements. Since 1932 they have acted as agents in Sweden for some of the products of Johnson Matthey. The company will in future be known as A/B Nyström & Matthey.

Russian forging journal

Abstracts from the Russian forging journal — Kuznechno - Shtampovochnoe Proizvodstvo, May, 1960, **2.** *This is the second year of this journal devoted specifically to forging. Abstracts of the more important articles are given in* METAL TREATMENT *each month.*

Choice of the optimum bite during cogging under plain tools. A. I. ROGOV. Pp. 1–3.
During free forging it is most important to determine the optimum bite for which the minimum number of blows of the hammer or strokes of the press will be needed to produce the required dimensions of the cross-section of the forging. Formulae are derived for calculation of the bite, and examples are given of its calculation for square and round billets.

Compression of tubes in a split die. V. N. FROLOV. Pp. 3–6.
An examination is made of the states of stresses and deformations in the wall of the tube and the action of frictional forces during compression in a split die. The compression factor is found to be dependent on the ratio of the tube wall thickness to the tube diameter.

Fixing the tolerances for forgings subjected to rough machining before heat treatment. V. A. AFONCHIKOV and G. I. KOZIS. Pp. 7–9.
Forging tolerances on forgings to be rough machined before heat treatment are compared with those fully machined only after heat treatment. Rough machining before heat treatment and later final machining is recommended.

A semi-automatic slide gauge for measuring the diameters of forgings on presses. O. D. BYCHKOV. Pp. 9–14.

Technical lubricants for stamping thin sheet steel. A. V. KOROLEV and I. V. PODLUZHNAYA. Pp. 14–17.
Tests were carried out to determine the ability of lubricants to create a strong and stable lubricating film during cold stamping. Varying amounts of talc were added to gun oil and a content of 60% by weight of talc produced the best results. Aluminium and oxides of Cr, Zn, Ni and Fe were also used as additions, and lubricants with an addition of nickel oxide had the greatest stability. The lubricants to which talc and nickel oxide were added required lower forces to produce slip between the plates on the test apparatus than lubricants in current use at automobile works. The latter were found to contain minute hard particles of silica causing abrasive wear on the tool. Lubricants with added talc may be successfully used for hot stamping also.

New technological upsetting processes at the Stankonormal works. I. A. NOVIKOV. Pp. 17–21.
Comparisons are made of the operation of imported presses (Petzer and Gateburg).

Choice of the temperature range for forging and stamping carbon steels. B. F. TRAKHTENBERG. Pp. 21–26.

A new horizontal hydraulic tube profiling press. V. I. FILIPPOV. Pp. 27–31.
A 3,150-ton (metric) extrusion press for steel tubes is described in detail.

Changes in National hot stamping, crank drive presses and comparison of these presses with those of other foreign firms. A. A. IGNATOV. Pp. 31–38.
Modifications to National presses are described and these presses are assessed by comparison with other presses produced in the Western World.

The use of a controlled drive in crank presses. B. N. MARKOVICH and A. K. MEL'NIKOV. Pp. 38–41.
Press drive control mechanisms employed in Western Germany and other countries are described.

The strength of the connecting rods of forging hammers. B. V. IVANOV and K. V. SEMENOV. Pp. 41–44.
Strain gauges were used to measure the stresses arising in the rods from the blow of the hammer, and examine the causes of fracture from the oscillograms obtained. A rigid coupling between the connecting rod and the hammer head increases the life of the rod.

Friction in the grooves of a disc brake. G. E. BRENEV. P. 44.
A simplified method is outlined for calculation of the clamp force, taking into account friction in the grooves, for disc brakes of crankdrive presses.

Bending of conical components in a vertical press. P. G. SHISHLAKOV. Pp. 45–46.

A new development in the fastening of blanking dies. P. M. PAVLOVICH. P. 46.
A description is given of a universal unit for setting and fastening the ram and dies of blanking presses.

A countersink in dies. L. I. VEGNER. P. 47.
Die designs are given for producing countersinks simultaneously with other press operations.

Hot stamping of components of large dimensions with the use of backing plates. A. A. LYUBCHENKO and N. T. ARISTARKHOV. Pp. 47–48.
The use of these plates is outlined for the stamping of covers of pressure vessels, etc.

An apparatus for extraction of components (from the die) during stamping. E. M. GIL'DINSON. P. 49.

Fatigue breakdowns in carbon steels

MIRKO KLESNIL

The article contains the results of research into the development of breakdowns in cohesion caused by fatigue in carbon steels with varying carbon contents after annealing. A study was made of hardening, and tensometers were used to measure the amplitude of the deformation and stress. At the same time the changes in the grain structure were studied by X-ray diffractography. In the elastically plastic zone, hardening is pronounced; in the phenomenologically elastic zone, which covers almost the whole course of the Wöhler curve, no hardening was established. In the elastic zone during loading above the fatigue limit, X-ray analysis revealed only inconsiderable changes in certain reflections. These phenomena occur up to a certain number of cycles, are not connected with fragmentation in the sense of static loading, and are depicted by areas of disintegrated ferrite. Optical and electron microscopy showed that these areas, which are represented by persistent slip bands, occur on the surface of a specimen in the deformation relief of the slip bands. If these bands attain critical dimensions, a microscopic crack will form in them, which expands, under the action of the high concentration of stresses, through the basic metallic component, and leads in the final stage to fracture of the specimen. This work was first reported in 'Hutnické Listy,' 1960, (2). The author is at the Laboratory for the Study of the Properties of Metals of the Czechoslovak Academy of Sciences in Brno

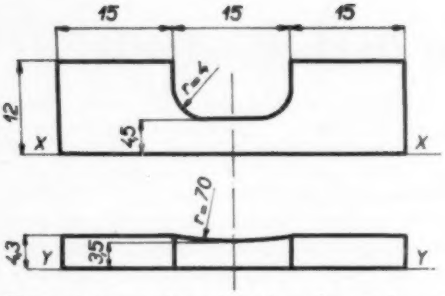
BREAKDOWN OF THE COHESION of metals through fatigue has already been known for over a hundred years. Nevertheless there exist a series of fundamental problems which have not hitherto been solved in this sphere of the strength of metals. At the present time these problems, which are one of the first steps towards fulfilling the requirements of economic construction, acquire exceptional importance. Practice likewise shows that the calculation of structural components cannot henceforth rest solely on a number of results obtained by conventional experiments. For such calculation it is necessary to be in command of the hitherto unrecorded influences of the shape, size, state of stresses, structure, etc. Apart from this it is necessary to choose such materials and such methods of treating them, as will suitably conform to the required production conditions.

The solution of these tasks, if we are to arrive at generally valid conclusions, must rest on data of the physical nature of the fatigue processes. In this way it is possible to arrive at true bases for the choice of a suitable material, its thermal and thermochemical treatment, and mechanical working. At the same time this road presents the only method by which to create for the mechanism of breakdown by fatigue, a model whose mathematical-statistical calculation can lead to a general solution which will express the strength conditions in relation to many of the factors mentioned above.

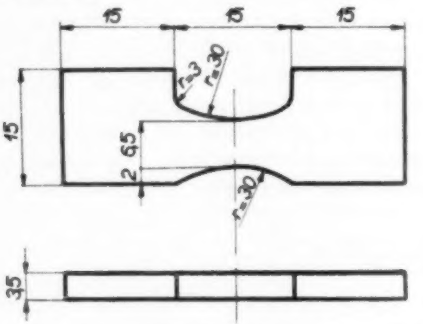
This work reports briefly on fatigue processes in carbon steels with various carbon contents, heat treated by annealing. This is part of a research task of the Laboratory for the Study of the Properties of Metals of the Czechoslovak Academy of Sciences in Brno.

Material and method of testing

Specimens were produced from normalized steels to specifications CSN 12010 (0·09% C), CSN 12040 (0·4% C) and CSN 19152 (0·8% C). After preparation, some specimens (fig. 1) were annealed *in vacuo* at a temperature of 600°C. for complete removal of internal stress which might arise during working; these were intended for the metallographic study and investigation of the fracture surfaces. The specimens which were intended for measurement of the degree of hardening and for X-ray study



1 *Shape of an experimental specimen for metallographic investigation of changes in the structure and the form of the fracture surfaces*



2 *Shape of an experimental specimen for measurement of the hardening and X-ray observation of changes in the structure*

(fig. 2) were annealed *in vacuo* at a temperature of 950°C. with subsequent free cooling in the furnace; by this treatment a suitable dimension of the metallographic grain was obtained. The specimens were loaded symmetrically with an alternating cycle of bending stresses by means of a spring dynamometer with a variable amplitude of the deflection on an experimental device of our own construction. The experiments were conducted at normal temperature without cooling the specimen.

The Wöhler curves for all the types of steels studied are given in fig. 3. The fatigue limit of CSN 12010 steel is ± 19 kg./mm.², of CSN 12040 ± 25·5 kg./mm.² and of CSN 19152 ± 31·5 kg./mm.²

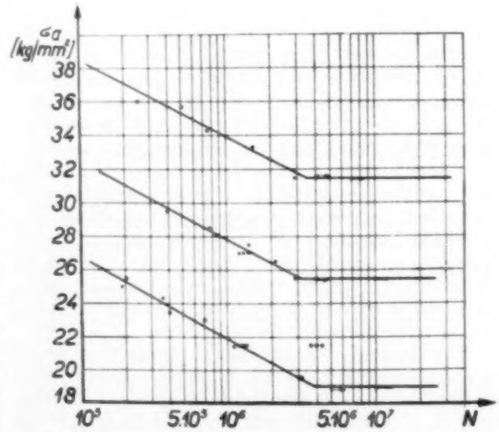
The actual tests consisted of cyclic loading of the specimens, one surface of which was mechanically polished and chemically etched in preparation for metallographic observation, and their metallographic and X-ray investigation in various stages of loading, with simultaneous measurement of the amplitudes of the stress and the deformation. The tests were supplemented by the results of a study of the fracture surfaces.

The changes in the structure were metallographically investigated in a Zeiss-Neophot optical microscope and in a table-type, electron microscope of Czechoslovak manufacture. The method of preparation of two-stage replicas with positive and negative shadowing for observation of a selected area in various phases of loading has already been described by Molčik and Klesnil.[1] The X-ray examination was carried out by the back reflection method. Filtered radiation from a cobalt anode was used.

For the measurement of the amplitude of the stress and the deformation use was made of tensometer recordings. The bridge was compensated by means of a cathode ray oscillograph to obtain higher accuracy in reading off the values.

Hardening and change in the structure of the steel during oscillating loading

For the study of hardening and changes in the structure use was made of specimens (fig. 2) produced from steel CSN 12010. It should be emphasized that the first traces of permanent plastic deformation in the external fibres were found by measurement up to a stress $\sigma_{co} = 28 \cdot 0$ kg./mm.² while the shear stress was found to be 21·5 kg./mm.², for it is known that the value of σ_{co} is a function of the strain gradient. From what has been indicated it follows that stress amplitudes at the fatigue limit and above it lie within the phenomenologically elastic zone. At applied cyclic loadings of $\sigma_a = \pm 19 \cdot 0$, $\pm 25 \cdot 0$ and $\pm 27 \cdot 0$ kg./mm.², no change in the amplitude of the stress or the deformation was measured. We can, therefore, assume that the whole range of the time-dependent fatigue limit is characterized by alternating deformation taking place without hardening.



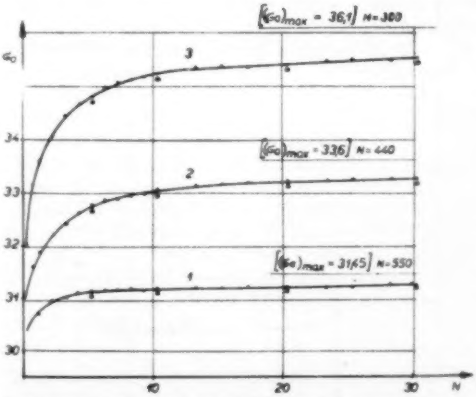
3 *Wöhler curves of the steels used:* σ_a *= applied stress;* N *= number of cycles*

Hardening of the steels was recorded only at amplitudes of the stress exceeding the shear limit of the outer fibres. In this instance at the selected amplitude of deflection of the spring dynamometer, the effect of hardening was manifested by a growth in the amplitude of the stress and a drop in the amplitude of the deformation. Three amplitudes of deflection of the spring dynamometer were chosen, which led to three maximum amplitudes of the stress on completion of hardening, namely $\sigma_{a\ max.} = \pm 31{\cdot}45$, $\pm 33{\cdot}6$ and $\pm 36{\cdot}1$ kg./mm.[2] The changes in the amplitudes of the stress in relation to the number of cycles are shown in fig. 4.

Hardening, which is at its maximum intensity during the first cycles of loading, later decreases, and is complete after 300, 440 and 550 cycles. With the decreasing amplitude of the stress there is an increase in the period within which hardening of the metal proceeds. It was measured on the one hand during gradual loading (static period—designation by a point), and on the other hand during loading with a frequency of 150 applications of load/min. (designation by a triangle). During loading with a frequency of 150 cycles/min. somewhat lower values were reached than during gradual loading (fig. 4).

These relationships show that the extent of the plastic deformation, in consequence of which hardening is manifested, is dependent on the rate of application of load. What has been shown is in agreement with the results of Bullen, Head and Wood,[2] who showed by means of X-rays on pure copper that the rate of fragmentation of the grains at a chosen amplitude of the stress is a function of the frequency of loading.

From fig. 4 it is evident that the rate of hardening decreases with the reduction in the amplitude of the stress, and at an amplitude of 27·0 kg./mm.[2]



4 *Change in the amplitude of the stress in relation to the number of cycles during hardening of steel* CSN 12010: σ_a = *applied stress;* N = *number of cycles*

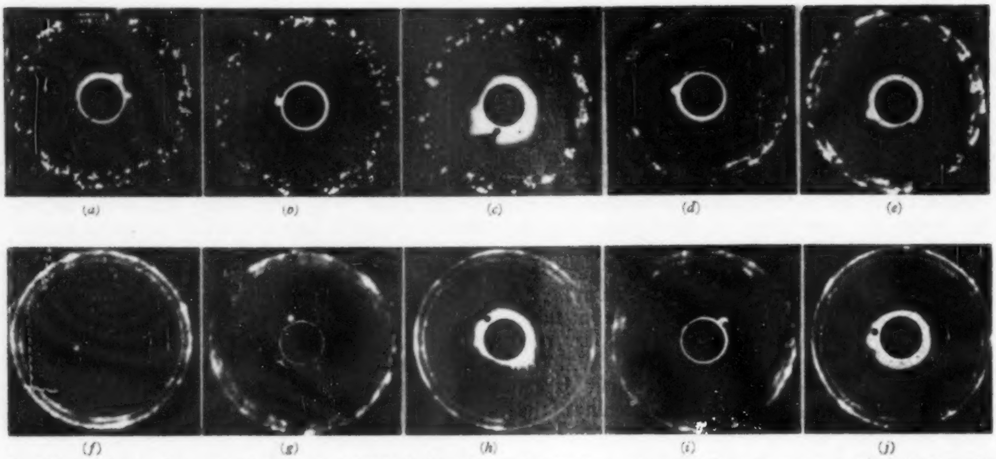
hardening was no longer recorded, despite the fact that even after a very small number of cycles ($N = 10^3$) fatigue slip bands occur on the polished surface of the specimen.[4] One of the basic features of the fatigue of steel is the occurrence of alternating plastic deformation without measurable hardening even in the zone of the time-dependent fatigue limit.

The results of the X-ray study completely confirm this assertion. Fig. 5 (*a*) shows that at the fatigue limit even after a high number of cycles no noticeable changes occur in the internal structure of the ferritic grains. But it must be called to mind that, even at a stress about 15% below the fatigue limit, at a higher number of cycles traces of alternating plastic deformation are apparent in some grains. Even at an applied stress $\sigma_a = \pm 25{\cdot}0$ kg./mm.[2] after a number of cycles of 10^4 it would be only scarcely possible to conclude the occurrence of indistinct changes in the internal structure of certain grains. At this stage the specimen was already covered with slip bands, which once again indicates the concept of homogeneous, alternating slip, taking place without hardening of the ferritic component.

In fig. 5 (*c*) is an X-ray microgram at the same amplitude of stress after a number of cycles of 10^5. At this stage certain reflections are diffusely manifested. This phenomenon is not a direct consequence of the inhomogeneous deformation, but of the formation of disintegrated zones of ferrite, represented on the surface by persistent slip bands, which are discussed in the rest of the article.

The microgram in fig. 5 (*d*) was obtained after reaching a number of cycles of $1{\cdot}85 \times 10^5$, *i.e.* closely before the fracture of the specimen. It illustrates the changes in the structure of the grains, through which the expanded cracks, which on the surface formed a complete network in the field of radiation by the X-rays, penetrated to a considerable depth. And in the same area of the specimen fracture already took place after the following 5×10^3 cycles. Likewise, too, during loading with an amplitude of $\pm 27{\cdot}0$ kg./mm.[2], within the first half of the number of cycles necessary for fracture, it is impossible to detect any more important changes in the structure of the grains. The process takes place just as at an amplitude of $\pm 25{\cdot}0$ kg./mm.[2], but it is shorter, since the number of cycles till fracture is less. Only during loading above the shear limit of the external fibres are changes shown on the X-ray diagrams analogous to the changes during static loading.

During loading in the elastically plastic state the chosen amplitude of deflection of the spring dynamometer was in accordance with the relationship of the amplitude of the stress to the number of cycles shown in fig. 4 (curve 1). The state of the structure after 550·5 cycles, *i.e.* in the stage where



5 *Micro- X-ray diagrams of steel* CSN 12010 *during alternating loading:* **a**, *applied stress* $\sigma_a = \pm 19 \cdot 0$ *kg./mm.*^{2}, $N = 12 \cdot 1 \times 10^6$; **b**, $\sigma_a = \pm 25 \cdot 0$ *kg./mm.*^{2}, $N = 10^4$; **c**, $\sigma_a = \pm 25$ *kg./mm.*^{2}, $N = 10^5$; **d**, $\sigma_a = \pm 25$ *kg./mm.*^{2}, $N = 1 \cdot 85 \times 10^5$; **e**, $N = 550 \cdot 5$; **f**, $N = 1{,}500$; **g**, $\varepsilon = 2 \cdot 4\%$; **h**, *after polygonization;* **i**, $\varepsilon = 2 \cdot 4\%$; **j**, $N = 5{,}000$

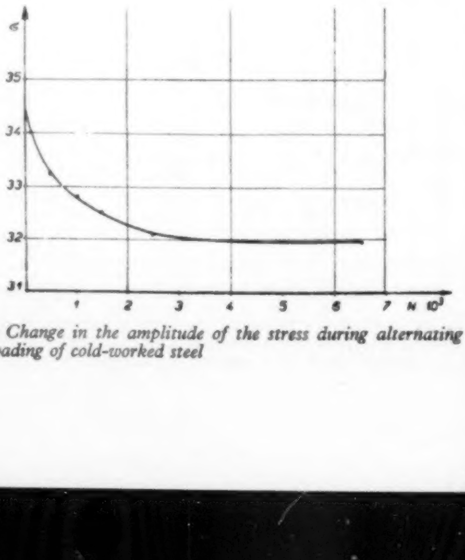
hardening was complete, is shown in fig. 5 (*e*). During further loading, which already takes place without hardening, additional changes in the structure are manifested as further disorientation of the reflecting volumes (fig. 5 (*f*)). The same resultant state was reached after 1,500 cycles and remained unchanged during further loading.

A similar sequence of changes in the internal structure was also obtained as a result of the use of higher values of the amplitudes of the deflection of the dynamometer with the hardening sequences expressed by curves 2 and 3 in fig. 4. The changes in the state of the structure were, however, complete within a shorter time, and fragmentation was much more apparent. Since it is first of all in this stage, after the completion of hardening and the changes in the structure of the grains, that the real fatigue process commences, which is manifested by the formation of fatigue, slip bands and by the formation of disintegrated zones of ferrite, as was shown by grinding away a thin surface layer, it can be judged that inhomogeneous slip changed into homogeneous slip, which did not lead to further changes in the structure, nor, therefore, to hardening.

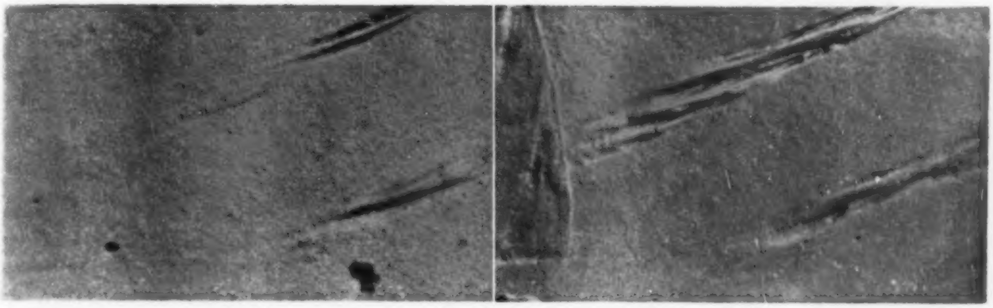
It is known that by annealing at the recovery temperature polygonization processes take place in cold-worked metal. As a consequence of this complex diffusion process there is also a change in the mechanical properties revealed by a fall in the hardness and the shear stress. A fall in the microscopic internal stress is manifested by resolution of the Kα doublet. The high disorientation of the reflecting volumes, however, remains preserved, and it is possible to eliminate it only by recrystallization or heating to the austenitization temperature with subsequent recrystallization.

In fig. 5 (*g*) is a picture of the state of the structure of a specimen loaded by static flexure to the elastically plastic state ($\varepsilon = 2 \cdot 4\%$). In fig. 5 (*h*) is shown the state of the structure of the same specimen after annealing at a temperature of 550°C. for a period of half-an-hour with subsequent gradual cooling (2°C./min.). On comparison of the two specimens the change brought about by the polygonization process is apparent. Apart from this, in fig. 5 (*h*) it is possible to observe isolated, sharp, diffraction patterns, which belong to the recrystallized grains, as the optical microscope confirmed.

Similar changes in the structure of cold-worked



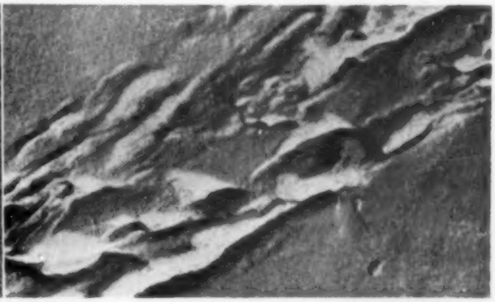
6 *Change in the amplitude of the stress during alternating loading of cold-worked steel*



(a) (b)

7 Development of slip bands in a selected area of a ferritic grain: CSN 12040; $\sigma_a = \pm 29 \cdot 0$ *kg./mm.*^{2}; $\times$ 11,000
a, $N = 3 \times 10^3$; **b**, $N = 5 \times 10^4$

8 Obstruction of the development of the slip bands in the ferrite by the cementite phase: CSN 12040; $\sigma_a = \pm 26 \cdot 5$ *kg./mm.*^{2}; $N = 2 \times 10^5$ $\times$ 20,000



9 Slip band with a series of submicroscopic breakdowns in the ferrite: CSN 12040; $\sigma_a = \pm 26 \cdot 5$ *kg./mm.*^{2}; $N = 10^5$ $\times$ 20,000

steel are produced, not only by annealing at the recovery temperature, but also by cyclic loading. In fig. 5 (*i*) is the X-ray diagram of the same elastically, plastically deformed specimen as in fig. 5 (*g*). The specimen deformed in this way was inserted into the test apparatus, on which was set the same amplitude of the deflection of the dynamometer, which had led to hardening at a value of $\pm$ 31·45 kg./mm.^{2} when applied to the annealed specimens (curve 1, fig. 4). During alternating loading the amplitude of the stress fell, and its course is shown in fig. 6. The changes in the structure observed by means of X-rays are in agreement with the softening of the material, as measured by the change in the amplitude of the external stress. In fig. 5 (*j*) is depicted the state of the structure after a number of cycles $N = 5 \times 10^3$. By comparison of fig. 5 (*i*) and (*j*) there is clearly a distinct difference, based on the drop in internal stress.

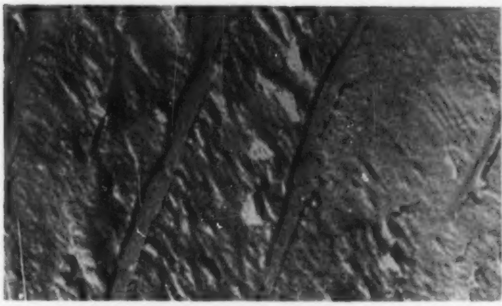
From what has been set out above, it follows that the processes taking place during recovery annealing are akin to the process taking place during cyclic loading of cold-worked material, as is shown by a comparison of fig. 5 (*j*) and (*h*).

Results of the metallographic study

The morphology of the relief which is formed by alternating, plastic deformation in the phenomenologically elastic zone, shows that alternating, plastic deformation has its origin in fine, homogeneous slip. With the increasing number of cycles the slip bands which form are widened, since each cycle contributes to the submicroscopic change in the relief of the slip bands.

Fig. 7 (*a*) and (*b*), obtained from the same area of a specimen with the use of the electron microscope, fully confirm this opinion.

The slip bands in steels to specification CSN 12010 and CSN 12040 are formed exclusively in the grains of ferrite. The grain boundaries (fig. 7 (*b*)) and especially the cementite lamellae of the pearlitic grains obstruct their development (fig. 8). The dark stripes with various orientations, which are manifested in the slip bands even in the initial stages of loading, may be shown by the negative method of shadowing to be submicroscopic breakdowns of the cohesion (fig. 9). The development of the deformation relief on the surface of the specimen and the formation of the first submicroscopic break-



10 *Relief of homogeneous plastic deformation in the ferrite lamellae of the perlitic grains:* CSN 19152; $\sigma_a = \pm 31{\cdot}5$ *kg./mm.*^{2}; $N = 10^6$ × 15,000

11 *Submicroscopic cracks in the ferritic component:* CSN 19152; $\sigma_a = \pm 34{\cdot}0$ *kg./mm.*^{2}; $N = 10^4$ × 17,000

12 *Persistent slip band in the ferritic component:* CSN 12010; $\sigma_a = \pm 25{\cdot}0$ *kg./mm.*^{2}; $N = 10^5$ × 15,000

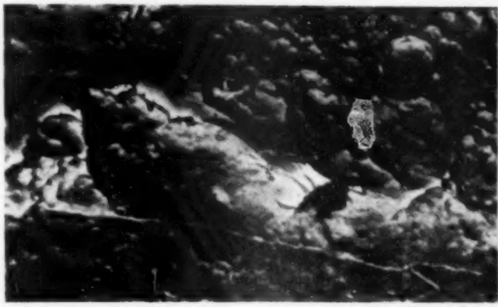
13 *Microscopic crack running within a persistent slip band:* CSN 12040; $\sigma_a = \pm 28{\cdot}0$ *kg./mm.*^{2}; $N = 2{\cdot}5 \times 10^5$ × 15,000

downs have been described in detail by Klesnil and Ryš[3]; the pattern of the formation of the surface relief as a result of slip in two slip systems has been authenticated by Klesnil.[4] With the increasing carbon content, plastic deformation starts to have its origin in the ferritic lamellae of the pearlitic grains also. The cementite lamellae remain unaffected by the alternating plastic deformation (fig. 10). By means of negative shadowing, it is possible to show the presence of the first submicroscopic cracks in the ferrite even at a number of cycles which is only 1% of the total number of cycles required to produce fracture (fig. 11).

Whereas the slip bands occurring during static loading may be readily removed by grinding away a thin surface layer (thickness $\leq 10^{-4}$ cm.), a definite part of the slip bands occurring during alternating loading still remains in evidence even after grinding away a thick surface layer. This phenomenon can lead to the conclusion that these 'persistent slip bands' are already microscopic cracks.[5, 6] The electron microscope, however, shows that the persistent slip bands are not microscopic cracks, but that they represent zones of disintegrated ferritic component. Persistent slip bands, after the grinding away of a surface layer of 2μ, are shown in fig. 12. With the increasing number of cycles the persistent slip bands are elongated, while the grains of pearlite obstruct their development.[4] After attaining the critical length (about 100μ), a microscopic crack is formed in the persistent slip band (fig. 13). Its formation probably takes place through the merging of submicroscopic cracks.

A micrograph of the fracture surface in the same area is shown in fig. 14. The fracture has the character of static fracture in mechanically worked material. The microscopic crack, which has been formed by the process already indicated in a disintegrated area of ferrite, expands further through the action of the high, local concentration of stresses at its root. On this account the pearlitic grains obstruct its development with a much lower degree of intensity than was shown by the optical microscope. The fracture surface, which was formed by the expansion of a microscopic crack in the area of disintegrated ferrite, is characteristic by reason of its ribbing (fig. 15).

Since, in our instance, symmetrical, alternating



14 *Form of a fracture surface from the zone at the edge of a specimen corresponding to a fracture in a disintegrated area of ferrite:* CSN 12010; $\sigma_a = \pm 21 \cdot 5$ *kg./mm.*² $\times$ 8,000

15 *Form of a fracture surface corresponding to expansion of a microscopic crack in ferrite in steel* CSN 12010: $\sigma_a = \pm 21 \cdot 5$ *kg./mm.*² $\times$ 8,000

loading by flexure was chosen, it might be possible to raise the objection that the formation of faults on the surface of the specimen is brought about by the high strain gradient. For this reason a polished, metallographic specimen was prepared of the x–x plane (fig. 1) with a linear sequence of the amplitudes of the stress. By means of an optical microscope it was shown that, in the range of stress amplitudes exceeding the fatigue limit, even in this plane persistent slip bands are formed, which expand into the interior of the specimen. We can, therefore, assume that the disintegrated areas of ferrite form in the reticulated, deformation relief of the slip bands.

Analysis of the results

On the basis of the study which has been conducted we can divide up the whole fatigue process into several main stages:

1. The period of hardening of the material. This was shown to exist only during loading in the elastically plastic state; in steels it is terminated in the zone of the time-dependent fatigue limit of the Wöhler curve, and in engineering practice it only rarely enters into consideration.

2. The period within which fatigue, slip bands are manifested on the surface, and within them are formed the first, submicroscopic breakdowns in cohesion.

3. The period within which there is formation and expansion of the persistent slip bands, representing disintegrated areas of the basic, ferritic component.

4. The period within which a microscopic crack is formed within the persistent slip bands; during subsequent loading this extends across the carrying cross-section, and leads to final fracture of the component.

In steels, cyclic loading proceeds within the whole applicable range of the Wöhler curve in the phenomenologically elastic zone. At selected amplitudes of the stress (19·0–27·0 kg./mm.²) no hardening was recorded, which could be manifested by a change in the external stress or the deformation. Similarly during an X-ray study, likewise no changes were discovered in the internal structure of the grains in the first stages of loading. In so far as they are manifested at higher numbers of cycles, it is possible to indicate simultaneously the existence of persistent slip bands down to a depth of 50μ. The opinion is justified that the changes in the reflection patterns of the grains do not arise as a result of fragmentation of the grains in the sense of static loading, but are manifested as an outcome of the disintegrated areas and of the microscopic cracks running within the ferritic background of certain grains. Only in this sense is it possible to comprehend the fatigue limit as a deformation boundary, and not as a boundary at which homogeneous slip is changed into inhomogeneous slip, as suggested by Möller and Hempel.[7]

It was shown that measurable hardening manifested by a change in the external stress and the deformation occurs only in the zone of elastically plastic deformations. The hardening is the greater and the time period within which it takes place is the shorter, the higher was the chosen amplitude of the deformation. The micro-X-ray diagrams show fragmentation of the grains just as during static loading. Hardening ends after a certain number of cycles, and further loading takes place without measurable hardening. In this stage, however, during the course of a certain number of cycles changes in the structure of the grains still take place, as was shown by micro-X-ray analysis. This phenomenon may be explained in two ways. It is possible that hardening takes place only in the outer fibres, and its effect cannot be recorded by a change in the external stress. As far more probable, however, the possibility presents itself that two

processes take place in the material. Fragmentation which restricts the rise in internal stress, leading to hardening, and polygonization, which is governed by diffusion processes taking place within a thin, surface layer, mutually compensate each other in their action.

From the X-ray study there follows the difference between the state of the structure during static and alternating loading above the shear limit of the outer fibres. Whereas during static loading, simultaneously with fragmentation, there is an increase in the internal, microscopic stress, the resultant pictures of the state of the structure during alternating loading are very similar to the states of the structure of polygonized material, as follows from a comparison of figs. 5 (*f*) and 5 (*h*). It is, therefore, possible to judge that during hardening under cyclic loading diffusion processes take place which are very similar to polygonization processes.

Both cyclic deformation without measurable hardening, and also the process of softening of cold-worked steel by cyclic loading, arouse once again doubts concerning the theories of Orowan and Afanas'ev,[6, 8] who suggest that the formation of breakdowns in cohesion is a consequence of hardening in the plastically deformed grains.

The appearance of the relief forming on the surface of a specimen shows that this differs basically from the phenomenon of plastic deformation during static loading. In the slip bands, even after a relatively small number of cycles, submicroscopic breakdowns in the cohesion form with completely random orientation. The slip bands are the nuclei of the disintegrated areas of ferrite, and expand relatively gradually into the interior of the basic metallic component. These areas are portrayed by the persistent slip bands, which are still prominent after grinding of the surface layer and after repeated etching. The whole process takes place up to a number of cycles, which is approximately half the total number of cycles required for fracture. Since even in the x–x plane (fig. 1) in the supercritically stressed zone persistent slip bands are formed, which expand into the interior of the specimen, and since, on grinding away the layers, no new persistent slip bands were discovered, we may premise that the reticulated, deformation relief of the slip bands is the one and only factor initiating the breakdown in cohesion through fatigue. Prolongation of the number of cycles required for fracture of the specimen by 333% (fig. 3) with grinding away of a surface 15μ thick after every $2{\cdot}5 \times 10^5$ cycles completely confirms these conclusions.

As soon as the disintegrated areas attain critical dimensions, a microscopic crack is formed, probably through the coalescence of submicroscopic cracks, which expands increasingly rapidly through the metal substance, and in the ultimate phase leads to fatigue fracture. In agreement with what has been set out in the foregoing, electron diffractography showed two different zones of fatigue fracture. Whereas with regard to the nature of the occurrence of the slip bands and the expansion of the submicroscopic cracks there are no disputes, the formation of the first submicroscopic, and therefore also persistent, slip bands is the subject of wide discussion. We surmise that the various microphysical patterns[8, 9, 10] can scarcely be verified experimentally in the immediate future. Investigation of fatigue phenomena shows that the whole fatigue process consists in the development of breakdowns in cohesion through fatigue even from the initial cycles of loading.

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'Annealing' world's oldest operating reactor

Oak Ridge National Laboratory successfully completed a three-day 'annealing' operation to remove stored energy from the Graphite Reactor, the oldest operating reactor in the world.

The annealing operation was the first for the 17-year-old reactor originally constructed to produce gramme quantities of plutonium. The laboratory, which has five other research reactors, is operated by Union Carbide Corporation for the U.S. Atomic Energy Commission.

Annealing of the Graphite Reactor is a procedure in which the graphite is heated above its normal operating temperature. The purpose of the annealing is to remove the stored energy which had accumulated during the many years of routine operation of the reactor.

The stored energy was released over Labor Day weekend by reversing the cooling air flow through the reactor, thereby heating the affected region and providing thermal motion to displaced atoms. During this operation, the air flow was decreased to one-half its normal 100,000 cu. ft./min. rate.

Hundreds of additional thermocouples were added for safety checks on temperatures of the fuel and moderator. In addition, the monitoring system was expanded to measure the reactivity of the air more closely.

The laboratory's Graphite Reactor, also known as the X-10 Pile, was constructed in 1943, and went critical at 5 a.m., November 3, 1943. The plutonium produced initially was used in a chemical pilot plant to evaluate the process for separation of plutonium from uranium. The design of the huge plutonium plant at Hanford, Washington, was based on this system.

Metallurgy in nuclear power technology

5. Fuel element canning materials—part II

J. C. WRIGHT, B.Sc., Ph.D., A.I.M.

The metallurgy of nuclear power materials is developing on such a wide front and so rapidly that it is difficult for the non-specialist metallurgist to keep abreast with its scope. Dr. Wright, Reader in Industrial Metallurgy, College of Advanced Technology, Birmingham, outlines the subject in a series of articles which are appearing monthly in this journal

BERYLLIUM

Extraction procedures

Beryl is the most important commercial beryllium mineral and is the crystalline form of beryllium aluminium silicate, $3BeO.Al_2O_3.6SiO_2$, containing theoretically 14% of beryllium oxide. The main sources are Brazil, Argentina and India; other commercial sources exist in South Africa, Southern Rhodesia, French Morocco, Madagascar, and South Dakota. Beyond simple hand-picking, the physical concentration of beryllium ore is difficult. Gravity concentration of beryl from gangue is not selective because their specific gravities are similar. An indirect flotation method has been developed for certain types of deposit, but is not universally applicable. In effect, beryllium must be concentrated by one of three main chemical methods.

In the fluoride process finely ground beryl is mixed with sodium silicofluoride and sodium carbonate flux and heated at 800°C. This produces a double fluoride of sodium and beryllium which may be leached from the gangue materials in the reacted mass by solution in boiling water. Beryllium hydroxide contaminated with sodium fluoride is precipitated from the solution with caustic soda. After filtration, the hydroxide is calcined to oxide at 800–1,000°C.

In the Degussa process fine beryl is reacted with excess lime at 1,500°C., and although complete fusion does not take place, much of the silica and alumina in the gangue is converted to calcium silicate or aluminate. From the reacted cake beryllium may be dissolved with sulphuric acid to yield a solution of beryllium, aluminium and ferrous sulphates. The aluminium may be precipitated as $NH_4Al(SO_4)_2$ by ammonium sulphate and, after oxidizing the ferrous ions, the iron may be precipitated in turn as ferric hydroxide, using calcium carbonate. The beryllium is finally precipitated as hydroxide, using ammonium hydroxide, then filtered and calcined. The resulting oxide is purer than that resulting from the fluoride process and is chlorinated in contact with carbon at 1,000°C. in a reaction vessel. This yields a solid beryllium chloride product, $BeCl_2$, which may be electrolysed in an externally heated stainless steel or nickel pot (fig. 28), which is made cathodic.

In this operation the beryllium chloride is dissolved in molten sodium chloride and the cell run at about 800°C., or in a eutectic mixture of alkali chlorides at temperatures as low as 400°C. The anode of the cell is usually graphite, and chlorine which is evolved in the process is led away. Beryllium is deposited on the cell wall in flake-like form of the order of 1 cm. across and about 0·01 cm. thick, or in dendrite form. In the flake form it is of interest to note that the basal plane of the hexagonal lattice of beryllium lies in the plane of the flake.

The beryllium deposit generally entrains electrolyte and is normally contaminated with sodium and chlorine. For nuclear purposes particularly, it is necessary to refine the flake because chlorine has an undesirable neutron capture cross-section (the neutron capture cross-section of beryllium is doubled by the addition of 0·001% of chlorine), and additionally subcutaneous chloride easily hydrolyses and may cause blistering and exfoliation of the metal surface. Vacuum melting the flake by induction heating in beryllia crucibles at 1,800–1,900°C. reduces the chlorine content to less than 20 p.p.m. It is also possible to ball-mill the beryllium flake mass to expose the chloride impurities and then leach them out with an agent such as

oxalic acid. This process is more economical from the refining point of view, but is less effective in that the chlorine level is reduced only to 200–300 p.p.m. However, this is satisfactory for many purposes, and the beryllium is still in powder form at this stage.

A further chemical concentration process, the sulphate process, leads to beryllium fluoride, which may then be thermally reduced with magnesium. In the sulphate process beryl is fused in an electric arc furnace at 1,700°C. and quenched into cold water. The resulting particles are ground to less than 200 mesh and treated with strong sulphuric acid to yield beryllium, aluminium and iron sulphate. After dilution and filtering off gangue minerals the aluminium and iron are selectively precipitated. The beryllium is then precipitated as hydroxide, filtered off and dissolved in ammonium hydrogen fluoride. From this solution the alkaline beryllium fluoride, $(NH_4)_2BeF_4$, may be crystallized. On calcining at 800°C. this double salt is broken down to yield beryllium fluoride, BeF_2. The magnesium reduction of BeF_2 involves heating beryllium fluoride with about 75% of the stoichiometric amount of magnesium to a temperature above the melting point of beryllium. This results in the metal forming globules which float on the surface of the melt of magnesium fluoride and excess beryllium fluoride. When the reaction is complete the metal and slag are poured into a graphite mould. The ingot and slag are broken down and wet milled to dissolve away the beryllium fluoride, which is re-used, and beryllium pebbles. The pebbles are remelted by induction heating in beryllia crucibles under vacuum and the melt cast into a graphite mould which has been previously outgassed.

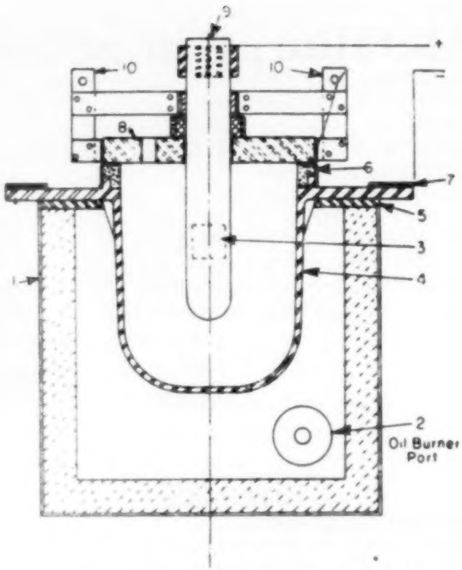
Electrolytic reduction does not compete in the U.S.A. with the magnesium reduction of beryllium fluorides, but the electrolytic process is favoured in Europe.

The brittleness of beryllium has been argued, by some authorities, to be due largely to the influence of impurities. Attempts have therefore been made to refine beryllium to very low impurity levels indeed, but these are by no means commercially acceptable processes yet.

Melting and casting

Beryllium is difficult in melting because it attacks most refractories. The two materials most commonly used for crucibles are beryllia and graphite, although there is some reaction with the latter. The best material at present is beryllia, but this is extremely susceptible to thermal shock and great care is required in handling it.

In addition to its reactivity towards refractories, beryllium reacts with most atmospheres and easily



28 *Apparatus for electrolysis of beryllium chloride* ('*The Metal Be*,' *A.S.M.*, 1955)

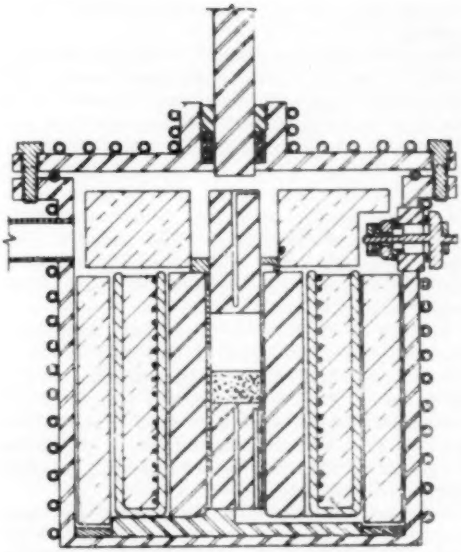
1	Tilting oil-fired furnace	6	Air-setting refractory ring
2	Oil burners	7	Cathode terminal
3	Combustion gas port	8	Refractory cover
4	Stainless-steel pot	9	Graphite anode
5	Cast-iron ring	10	Anode terminal

forms oxides, nitrides and carbides. It is therefore necessary to use an inert atmosphere or vacuum during melting. Inert gases must be especially pure and in practice considerable use is made of vacuum melting, in spite of the fact that beryllium has a very high vapour pressure at suitable melting temperatures. A useful compromise is to heat under vacuum to a temperature just below the melting point and then under a partial pressure of clean inert gas while melting is actually taking place. The vacuum heating below the melting point allows fluoride and chloride fluxes and also magnesium to distil off to some extent.

As far as fuel is concerned, electrical heating is the only possibility owing to the reactivity of beryllium. Normally induction heating is applied, using a susceptor of molybdenum or graphite since the coupling with beryllium alone is poor. The power coil has been placed within and outside the vacuum system with success in both cases.

The consumable-electrode electric arc melting method has also been applied to compacted beryllium successfully.

In casting beryllium, consideration has to be given to suitable ingot mould materials. Cast-iron moulds are not suitable because beryllium reacts with the graphite, but mild steel is reasonably



29 *Apparatus for compacting powders at elevated temperatures 'in vacua'* ('*The Metal Be*,' *A.S.M.*, 1955)

satisfactory. Degassed graphite moulds are acceptable and may be protected in addition by ceramic inserts. Beryllium ingots show little piping and even this can be overcome by the use of 'hot-tops.' Beryllium ingots have a tendency to cracking on cooling, due to the easy cleavage of the metal along the basal plane coupled with the fact that cast beryllium has a coarse grain size. It is possible to produce a finer grain size by fast cooling the ingot, but this aggravates the internal stresses and assists the cracking mechanism.

Cracking can be minimized by finding the optimum cooling rate for a given section, using hot-tops, and allowing the mould to collapse in sections where there is any restriction to normal shrinkage. Certain alloying elements tend to increase and others to decrease the cracking propensity. Iron is detrimental for instance, and aluminium ($\frac{1}{2}$–1%) reduces cracking. Even after taking precautions, as-cast beryllium ingots are coarse grained and very brittle. Very little mechanical deformation of the ingots is possible, being limited to very mild deformations by hot pressing and some simple extrusions. The main purpose of the ingots is as a source of material for powder metallurgy operations.

The powder metallurgy approach

The cast ingots are machined to swarf and because of the inherent brittleness this is easily reduced to 200-mesh powder in a ball mill. During swarf production it is important to minimize oxidation so no lubricant is used and usually a clean inert atmosphere is employed. During ball milling a further source of contamination is the steel mill surface and the grinding ball surfaces. There are two ways of overcoming this and both may be applied together. The mill and ball surfaces may be lined with beryllium and the beryllium powder which results may be leached with oxalic acid which will remove surface oxide and iron contamination.

There are three methods of compacting beryllium powder: (i) cold pressing and sintering; (ii) warm pressing and sintering; and (iii) vacuum hot pressing. The theoretical density of beryllium is $1 \cdot 85$ g./cm.^{3} By using high pressures, up to 80 ton/sq. in., on cold beryllium powder densities of the order of $1 \cdot 6$ g./cm.^{3} are obtainable, and by vacuum (10^{-5} mm. Hg) sintering at 1,000–1,200°C. the density may be increased to $1 \cdot 8$ g./cm.^{3} Sintering does not begin below 900°C. and is very sensitive to surface contamination of the powder. The difficulties of this process are the high press capacity required and the separate provision of a vacuum in sintering. The use of high vacua introduces the difficulty of the presence of beryllium vapour which may react with refractories or condense in the coolest part of the system.

Warm pressing involves compacting the beryllium at temperatures in the range 300–650°C., which is below the recrystallization temperature for beryllium. The pressures required are lower than those required for cold pressing and generally in the range 25–50 ton/sq. in. It is possible to achieve near theoretical density by this method. Pressing dies are a problem in view of the combined temperature and pressure, but conventional die steels may be used at temperatures up to 600°C. with a pressure of 25 ton/sq. in. Vacuum sintering of the green compact follows as for cold pressing.

The size of sintered compact which may be produced successfully by either cold or warm pressing and sintering is small and neither method is really satisfactory on a production basis. In contrast, vacuum hot compacting at 1,050°C. has been used to produce very large pieces of beryllium. Vacuum hot compacting is carried out in a vacuum of 10^{-1} to 10^{-2} mm. at a temperature of 1,050°C. maintained in a sealed and heated retort (fig. 29). Inside the retort a steel die is closed and pressed by hydraulic jacks actuated from outside, with the plungers passing through vacuum seals in the retort walls. The die is filled with powder prior to heating the retort and vibrated to achieve good packing, the final powder charge being possibly several hundred pounds. The time cycle of the whole process varies from a few hours up to five days, depending on the size of the piece. It is possible to shorten

the times by increasing the pressure, but this procedure leads to anisotropy in the resulting compact. Blocks measuring about 60 by 20 by 5 in. have been produced by this method.

Another process for compacting beryllium, at present being developed, is pressureless sintering, which gives densities of 95–98% of the theoretical. Beryllium powder of a critical size distribution is vibrated down in a graphite mould and the filled mould is heated at 1,200–1,220°C. for several hours in vacuum. Linear shrinkage of the powder averages about 20% for simple shapes, but the shape of the mould cavity is faithfully reproduced. Bars, cylinders and rectangular blocks may be produced by this method.

Finally, it is possible to hot work sheathed beryllium powder. A sheath or 'can' is loaded with beryllium powder by vibration and cold pressing. The can is then evacuated before sealing. The sealed mass may then be hot-worked at temperatures of the order of 900–1,100°C. by rolling, forging or extrusion. Closed die working is preferable, otherwise the can has to be thick enough to withstand lateral tensional stressing. Mild steel is a suitable canning material since it does not alloy significantly with beryllium in contact with it at temperatures below 1,050°C. For all sheathed working techniques it is advisable to achieve a high initial packing density so that the amount of working needed to achieve maximum final density is small. In this way the cans are distorted as little as possible and inward folding is minimized.

Fabrication of compacted beryllium

Beryllium is very difficult to fabricate and almost all methods rely on working the metal at temperatures above the recrystallization temperature. The amount of cold working which may be carried out is very restricted but some warm working is possible, particularly by slow extrusion.

The most commonly used fabrication method is extrusion (see fig. 30). The metal is sheathed in a mild steel can which may be evacuated, sealed and extruded at about 1,000°C. Although steel and beryllium have similar extrusion characteristics at 1,000°C. it is advisable to use a conical approach to the extrusion die to ensure concentricity at the start. The steel sheathing can be removed by peeling or by pickling in nitric acid, and dimensional tolerances on simple sections are good. Even so, both tolerance and surface finish are inferior to extrusion of the bare metal, but this latter process may be carried out only slowly and at temperatures of 400–450°C., using very high pressures. Sheathing of beryllium for extrusion at higher temperatures has the advantages of minimizing oxidation, preventing galling between the work and the die, and overcoming a health hazard problem.

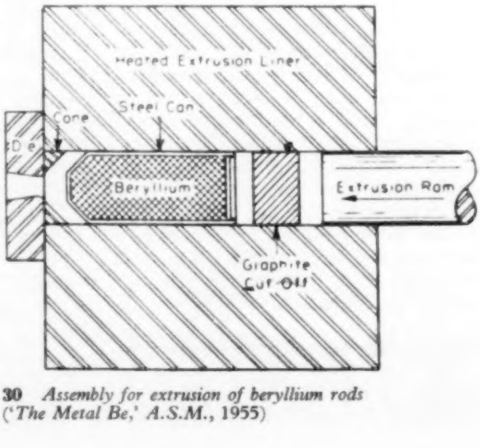
Steel sheathed beryllium is hot-rolled at 800–1,050°C., using a sealed picture-frame arrangement of steel sheet whose thickness must increase as the intended final reduction of the compact increases. Once some hot deformation has been obtained it becomes feasible to achieve reductions of as much as 50% between anneals and 10% between passes, the main difficulty being that of maintaining the correct working temperature. Thin sheets are best pack-rolled and since cold rolling is difficult if edge cracking is to be avoided, the bulk of the reduction is done hot.

Forging of beryllium is most easily carried out in closed dies at 600–1,000°C. and with the beryllium heavily sheathed. A limited amount of cold sizing can be carried out on small pieces. Warm drawing techniques have been used although care must be taken with lubrication to avoid galling and the extent of reduction before annealing becomes necessary is not large.

Annealing of beryllium to develop optimum properties is achieved in the range 700–950°C. The recrystallization temperature of heavily deformed material is normally above 700°C., and at about 900°C. beryllium undergoes grain growth which slightly lowers the strength and ductility of the metal.

Machining

Cast beryllium can be machined but the anisotropy of the coarse grains inevitably leads to a poor finish. Because of their finer grain size sintered powder compacts give a better finish. On the other hand, powder products are likely to contain more oxide which is very abrasive and this limits severely the life of high-speed tools to the extent



30 *Assembly for extrusion of beryllium rods* (*'The Metal Be,' A.S.M.*, 1955)

that it may be advantageous to use carbide-tipped tools. The use of lubricants has advantages from the point of view of ease of machining and greater protection of the health of the operator, but since beryllium swarf is comparatively valuable and must be re-used, machining lubricants must be thoroughly removed from swarf to avoid contamination.

Joining

In welding beryllium to beryllium by fusion an inert atmosphere is essential and the properties of the weld bead are not very good. Provided the weld bead is not expected to carry high stresses autogenous Argonarc welding of beryllium using an inert electrode or electron beam welding are feasible methods. Filler rod techniques are disappointing. Solid phase pressure welding of beryllium to beryllium is possible at temperatures above about 800°C. and the properties of the weld are generally better than those of a fusion weld. As with most pressure welding processes, cleanliness and relative movement of the two contact surfaces are essential for success.

Brazing is probably the best method of joining beryllium to beryllium and to other metals for normal temperature applications. The brazing materials used satisfactorily are aluminium and eutectic aluminium-silicon alloy. Inert atmosphere coverage is essential during the operation.

Electron beam welding has been used for welding beryllium to other metals.

NIOBIUM

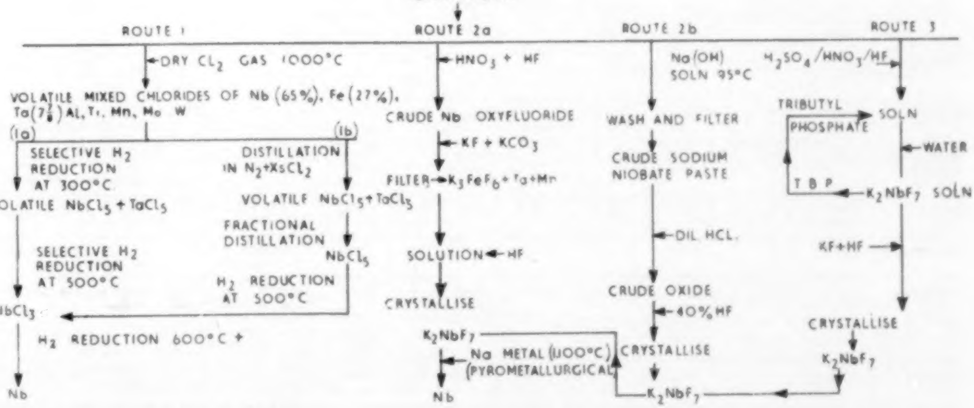
Extraction and fabrication

Niobium has an effective neutron capture cross-section for thermal neutrons of 1·15 barns, which is on the borderline for satisfactory use in thermal reactors. Its neutron capture cross-section in fast neutron fluxes is much more attractive and the metal is of considerable potential use in liquid metal-cooled reactors. Although niobium has been used in a ferro-alloy form for many years it has not been available in elemental form in any appreciable quantity until recently.

Starting with commercially available ferroniobium, a variety of routes has been investigated with a view to producing pure niobium metal. It would be inappropriate to pursue these developments in details, but an outline of some of them is given below in the form of a flow-sheet (fig. 31). It will be seen that the ferroniobium may be (1) chlorinated and the mixed chlorides separated by (*a*) selective reduction or (*b*) fractional distillation to yield niobium trichloride which may be reduced to niobium with hydrogen; (2) attacked with mixed acids and potassium niobium fluoride crystallized out after purification by either (*a*) selective precipitation or by (*b*) solvent extraction in tributyl phosphate—the K_2NbF_7 may then be reduced pyrometallurgically with sodium to yield niobium; (3) attacked with caustic alkali, precipitation and leaching of the residue with HF to yield a solution of K_2NbF_7 and reduced with sodium.

Extraction of niobium from niobium pentoxide by reduction with aluminium, carbon or niobium carbide, or calcium plus iodine, have been reported. Also niobium carbide has been chlorinated at 500°C. to yield niobium pentachloride which may be reduced with magnesium. In addition, fused niobium oxyfluoride has been electrolysed to yield niobium.

Development of extraction methods continues



31 *Flow-sheet—production of niobium*

and it is not yet possible to assess their potentialities and economics on a production scale in detail. Induced radioactivity resulting from irradiation of niobium is low, but that in tantalum, which tends to associate with niobium throughout extraction processes, is much higher. Thus niobium for reactor purposes must normally be free from tantalum and extraction processes must allow for this.

The extraction routes produce niobium in powder form, which contains various amounts of oxygen, carbon, nitrogen and hydrogen, in addition to small quantities of metallic impurities. In consolidating niobium powder by accepted powder metallurgy methods, some purification of the metal is achieved particularly during vacuum sintering. Oxygen, for instance, increases the hardness and brittleness of niobium and increases the difficulty of consolidation and subsequent fabrication so that it is desirable to remove as much oxygen as possible. Oxygen itself is evolved during vacuum sintering at temperatures over 2,000°C. or as carbon monoxide at temperatures of the order of 1,700–1,900°C. If the carbon content of the niobium powder prior to compacting is low, it is beneficial to add carbon to the raw powder in an amount dependent on the oxygen content so that advantage may be taken of the lower temperature of carbon monoxide evolution.

Table 11 shows the improvement in purity of niobium after sintering and rolling. Very efficient and large capacity pumping systems are required because large quantities of hydrogen, carbon monoxide and oxygen are evolved during vacuum sintering. Additionally, niobium powder is a very good getter for oxygen and nitrogen and absorber of hydrogen, and so extremely low partial pressures of these gases must be maintained for their removal. Induction or direct-resistance heating is used to attain sintering temperatures of the order of 2,000°C.

Compacted and sintered niobium powder may be worked conventionally or consumable-electrode arc-melted *in vacuo*. Because of the gettering potential of niobium the arc furnace vacuum must be very good and this leads to difficulty in stabilizing the arc. To minimize these difficulties high arc currents at low voltages are used and the electrode melting rate is high. Thus, there is only limited opportunity for further purification during melting because of the short time between melting and freezing of any one part of the niobium. Powder compacts may also be melted on a small scale by electron bombardment yielding niobium with low gas contamination and correspondingly low hardness.

TABLE 11 *Analysis of niobium powder and sheet rolled from sintered bar (from O'Driscoll and Miller, 'J. Inst. M.,' April, 1957, p. 384)*

	Powder weight %	Sheet weight %
C	0·25	<0·01
O	0·50	0·05
N	0·07	0·01
Ta ..	0·30	0·30
Si	0·08	<0·01
Fe ..	0·05	0·05
Pb ..	0·10	0·005
Ti ..	0·05	0·05
Sn ..	0·08	0·08

TABLE 12 *Some properties of canning materials (see last month, page 449)*

Material	Melting point	Thermal neutron capture c/s, barns	Thermal conductivity cal./sec./°C./cm.	Coefficient (R.T. –300) of thermal expansion in./in./°C. × 10⁻⁶	Tensile strength ton/sq. in.	Corrosion resistance				Application
						High temp. CO_2	High temp. water	Liquid metals		
Aluminium	660·2	0·215	0·503	25·0	6–10		Poor over 350°C.			Low heat release CO_2 or water cooled; 350°C.–
Beryllium	1,283	0·01	0·36	14·44	26·3–34·8†	Good	Poor	Poor		High-temperature gas-cooled reactor; 600°C.–
Magnesium Magnox A 12	650	0·06	0·411 0·276	26·0	10–12 9·5	Satisfactory		Very poor		Moderate to low-temperature CO_2 cooled, better than Al; 470°C.–
Niobium	2,468 ±10*	1·1	0·13	7·31	17·6	Poor	Excellent	Good	Compatible with uranium	Liquid metal cooled fast reactor
Vanadium	1,900	4·8	0·074					Good	Compatible with uranium	Liquid metal cooled fast reactor
Zirconium	1,852	0·18	0·05	7·61	25·0	Poor above 400°C.	Good	Poor, particularly above 600°C.	Zircaloy 2 improved water resistance and weldable. 0·5% Cu + 0·5% Mo improve CO_2 resistance	High-temperature water cooled
Stainless steel						Good	Good	Good	Reacts with U at high and with good contact	High-temperature fast reactors

*T. H. Schofield, *J. Inst. Met.*, April, 1957, p. 373 † Extruded flake

Consolidated niobium may be worked by conventional methods, but hot working is generally avoided because of the contamination problem at higher temperatures. Fortunately, niobium is very ductile and work hardens slowly so that cold reductions of at least 90% can be made before annealing is necessary. If hot working or annealing operations are necessary the metal must be either vacuum sealed in sheaths or contained in high vacuum furnaces with very low leak rates. In spite of the ease of working niobium, the full annealing temperature is above 110°C. Any heating method consistent with maintaining high vacuum may be used, but the relatively rapid heating and cooling rates obtained with the high-frequency method are advantageous.

Processes in which niobium is passed through a die such as wire drawing, deep drawing and probably extrusion involve the difficulties of seizing and galling. Protective coatings are required to act as a carrier for relatively still lubricants such as sulphonated tallow or drawing waxes. Dies may be made of hard chromium-plated steel but are frequently of aluminium bronze, tungsten carbide or beryllium copper. The normal starting point in thin-walled tube production is a disc blanked from sheet which is cupped and deep drawn. The deep drawn shell is then converted to tube of smaller diameter and thinner wall by conventional draw-bench methods.

Homogeneous welds in niobium can be made by resistance welding or by the Argonarc process; it may be welded to certain other metals by the same methods. The atmospheric protection required in resistance welding depends on the duration of each welding cycle. For instance, spot welds may be made in air, but seam welds are made under water. Properly made welds are ductile and almost as strong as the base metal. Atmospheric protection with Argonarc welding of niobium must be continued to lower temperatures than with most metals, usually to about 200°C.

Standard machining operations are applicable to niobium but care must be taken to minimize seizing and galling. Heavy cuts are preferable, using high-speed tools at high cutting speeds and with adequate clearance around the cutting edge, whether it is a lathe tool, milling cutter, tap or die, etc.

Multi-specimen creep testing machine

THE RESEARCH AND DEVELOPMENT department of the United Steel Companies Ltd. has designed a compact creep testing machine which is now being built and marketed by Distington Engineering Company Ltd., of Workington, Cumberland. It is expected to have many applications in industries concerned with the design and manufacture of steel parts for service conditions in steam boilers and turbines, gas turbines and certain chemical plant.

Known as the Unisteel multi-specimen creep testing machine, it is designed to accommodate either four high-sensitivity tests or twelve stress-to-fracture tests on the one machine, with one furnace and one temperature controller. The machine incorporates four loading systems, each of which caters for one high-sensitivity test or three stress-to-fracture tests in series.

Many years of experience in the use of creep testing machines have gone into the design and construction of the new model, a special feature of which is the concentration of a number of testing stations within a comparatively small space. The machine occupies a floor space of only slightly more than one square yard and can be installed in rows at 4 ft. centres. This compares very favourably with the usual single specimen machines, while the machine cost per test point is competitive with other machines on the market. For compact installations, guards can be fitted to prevent accidental contact with the loading weights.

The Unisteel machine can be used for the application of loads up to three tons on a specimen. The complete unit comprises the creep testing machine itself; a furnace consisting of a fused silica tube wire wound in three zones for resistance heating, encased in a polished stainless steel cylinder; a control panel, incorporating an electronic temperature controller; and two auxiliaries—a ratchet spanner and lifting jack—which can be used with a number of machines.

First known gramme quantities of osmium isotopes

The first known separation of gramme quantities of osmium isotopes has been accomplished by an electromagnetic process at Oak Ridge National Laboratory. The laboratory, principal supplier of radioactive and stable isotopes in the nation, is operated by Union Carbide Corporation for the U.S. Atomic Energy Commission.

Of the approximately 290 stable or relatively long-lived naturally occurring isotopes of 86 elements, 265 isotopes of 58 elements have now been enriched by the electromagnetic process. The isotopes of the inert gases neon, krypton, and xenon will be separated by thermal diffusion. Hydrogen and helium isotopes are available from other sources, while 23 of the elements have only one stable form.

Hence the separation of osmium isotopes completes the first phase of the stable isotopes programme at Oak Ridge—the collection of small quantities of enriched isotopes of all the elements originally scheduled for separation by the electromagnetic method.

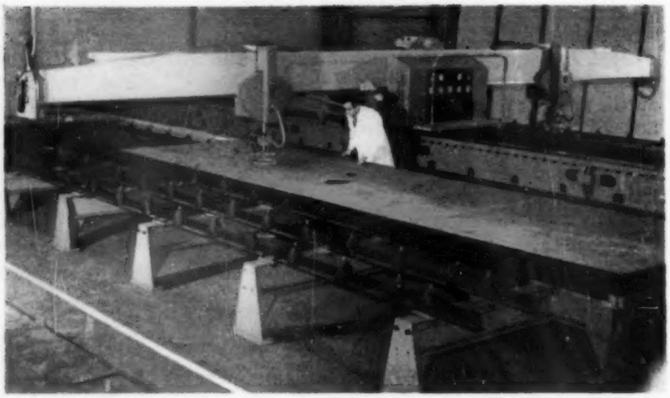
Previously, the difficulty in processing significant amounts of osmium was due to the extreme toxicity of osmium oxide. A very minute amount—10 millionths of a gramme in a cubic metre of air—can cause lung congestion and eye damage.

Since the vapour pressure of metallic osmium is very low, it was necessary to use the volatile, although toxic, osmium oxide as the feed material.

Metallurgical research at high pressures

Dr. J. E. Hilliard, of the Research Laboratory, General Electric Co., Schenectady, U.S.A., is to give a lecture on 'Metallurgical research at high pressures,' under the auspices of the Metal Physics Committee of the Institute of Metals. The meeting will take place at 17 Belgrave Square, London, S.W.1, on Thursday, January 12, 1961, at 6.30 p.m. Visitors are welcome; tickets are not required.

Computer-controlled gas-cutting machine



The first of the automatic cutters for ships' plate at the Edmonton works of the British Oxygen Co. Ltd.

In 1957 British Oxygen Co. Ltd. announced the development in association with Ferranti Ltd. of a computer-controlled gas-cutting machine designed for shipyards and large engineering works. An intensive programme of development has continued on the detailed problems involved and the first of two full-scale machines has successfully completed its acceptance trials at the Edmonton works of B.O.C. ready for transport to the Wallsend-on-Tyne shipyards of Swan, Hunter & Wigham Richardson Ltd. for commissioning trials.

Although the development is aimed particularly at shipyards, attractive savings in time and cost are also envisaged in other fields where there is wide use of profiled steel plate, for example, marine and structural engineering, locomotive building and the atomic energy programme.

Computer programming

In the drawing stage, dimensional information in co-ordinate form is tabulated relative to a chosen origin. The next step is to write this data in computer language on a planning sheet. From the planning sheet a punched tape for input to the computer is prepared by simple copy typing. The tape is then sent to a computer centre for the preparation of a magnetic tape to be used on the machine.

The computer, which may be at a computer centre serving a number of users, consists of a Ferranti Pegasus general-purpose computer plus a digital differential analyser.

The use of a computer reduces the amount of programming required to a minimum. Subroutines for repetitive shapes can be stored in the computer's memory and called up as required by the programmer using a simple code reference.

The machine

When the magnetic tape is played back in the machine control console the recorded trains of pulses are utilized to control the movement of the machine cutting heads.

The machine itself is of the port and starboard type capable of cutting two mirror-image 12 × 40-ft. plates simultaneously. A maximum thickness of 3 in. is at present envisaged. Power-driven roller-tables with retractable stops to locate the plates relative to the datum position of the cutting heads can be installed to bring the plates from the loading area to the cutting area and out again to the discharge area after profiling.

In addition to controlling the movement of the cutting head, all other functions are controlled automatically. These are: (1) gas control; (2) automatic ignition of the pre-heating flame; (3) continuous nozzle height control; and (4) flame monitoring. In the event of failure the machine is instantly shut down automatically.

Incentive for eye protection

British industry is now being offered an incentive plan to help reduce needless and costly eye accidents. For November saw the launching of the 'Wise Owl Club' of Great Britain, under the sponsorship of the British Safety Council.

The Wise Owl Club is sponsored internationally by the National Society for the Prevention of Blindness, New York, and is open to all who have saved their sight by wearing the proper protective eye equipment at work.

Wise Owl Chapters can be formed by any industrial concern in Great Britain. To form the Chapter, a firm completes a simple application form and receives its charter free. There need be no eligible employees in the firm when this application is made.

Total serious eye injuries in British industry for 1959 were 6,680, of which 2,670 were in general engineering and 1,150 in metal processing.

NEWS

Iron and Steel Board—prices

THE IRON AND STEEL BOARD announces that the prices of some specifications of iron and steel products have been increased whilst others have been reduced; the greater number of prices remains unchanged. Certain extras and allowances have been revised.

The changes include increases in the maximum prices of high-phosphorus foundry pig iron, of certain specifications of hot finished tubes and non-alloy bright bars, and reductions in alloy bars, stainless steel, cold-rolled strip and forging quality billets (soft basic forging billets reduced from £38 10*s*. to £38/ton).

Overall, the changes made do not represent any increase in the general level of iron and steel prices, nor do they represent any significant reduction. This confirms the forecast made in the board's announcement of October 25 concerning the effect on iron and steel prices of the recent rise in coal and coke prices.

The new determination came into force on November 28.

A number of presentational changes have been made in the price schedules. Among them is a more consistent use of the term 'basis price.' In the past the description 'basis price' has not for all products been applied to the price for the largest quantity. In future the price for the largest quantities of all heavy steel and re-rolled products will be called the 'basis price.' It will be equivalent to the former basis price less former allowances for quantity where these were applicable.

In consequence the price schedules for heavy steel and re-rolled products will not in future contain provision for allowances for quantity, but there will be extras for smaller quantities.

British conference in Belgium

A one-day conference was held recently in Brussels by High Duty Alloys Ltd. Three papers were read, dealing with both the technical aspect and applications of H.D.A. products, with particular emphasis on Hiduminium alloys.

The conference was opened by the Belgian agent of High Duty Alloys, Mr. Paul Alexis of S.A. Aciers Alexis, and the first paper to be read and discussed was on 'Close-to-form and close tolerance forgings.' This paper, presented by Mr. E. W. Peel, divisional manager of H.D.A.'s Forging Division at Redditch, covered not only the forging of Hiduminium alloys but also of steel, nickel-based and titanium alloys. The second paper, 'Interesting applications for rolled, extruded and drawn products,' was given by Mr. H. J. Davies, development manager.

The third paper dealt with the use of H.D.A. 'Forgings in nuclear engineering.' The speaker was Mr. E. T. Stewart-Jones, development engineer of the Forging Division. Again, as in the first paper, it dealt with the use of practically every material that was forgeable.

Change of name

The Electric Resistance Furance Co. Ltd., a member of the Efco Group of companies, has changed its name to Efco Furnaces Ltd. The change has become desirable due to the increased scope of the company's interests which were originally confined to electric resistance heating but have in recent years been widened to include both gas- and oil-fired furnaces.

London evening courses

The Borough Polytechnic, Borough Road, S.E.1, Division of Metal Science, is holding two special courses in the spring term of the 1960-61 session.

(I) 'Recent developments in non-electrolytic metal finishing.' A course of six weekly lectures, Thursdays, at 7 p.m., from January 12, 1961.

(II) 'Metallurgy of rarer metals.' A course of six weekly lectures, Tuesdays, at 7 p.m., from February 7, 1961.

HANDLING HOT FORGINGS

THE NEW LIGHT FORGE of Walter Somers Ltd., at Halesowen, near Birmingham, is equipped with the most up-to-date plant, including an automatic 500-ton press, a rotary furnace to serve it and a pair of automatically controlled heat-treatment furnaces for normalizing or annealing the finished forgings. Equal care has been devoted to handling the forgings both before forging and when hot. Forgings are moved from press to heat treatment by means of a large stillage truck, made by Lansing Bagnall Ltd., Basingstoke, with a capacity of three tons, and a platform length of 7 ft. The hot forgings are placed on the stillage by the press manipulator.

Furnace loading is in progress in the background. The forgings are placed on the trolley at the centre, which is fitted with a firebrick hearth, and runs on rails. It is simply pushed into and pulled out of the furnace doors at the right by the small tractor at the left.

NEW PLANT

Gas-fired rotary furnace

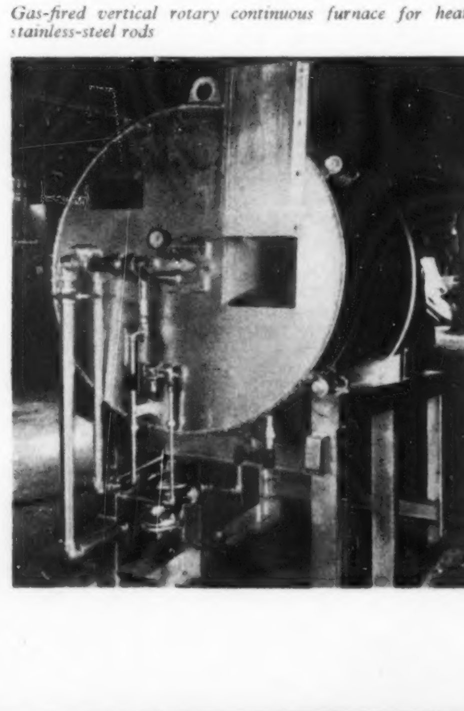
Dowson & Mason are now supplying in this country a gas-fired rotary furnace designed and developed by their American associates, the National Furnace Corporation of Providence, R.I. The furnace was designed primarily for heating stainless steel rods prior to rolling to knife-blade thickness in a standard rolling mill, but has many other industrial applications.

The furnace body is a welded steel cylinder, with a 7½-in. thick refractory lining, and stands on an angle-iron frame. Inside the furnace chamber is a spider carrying 12 alloy cups, each 4¼ in. i.d. and 10 in. long. The spider, which slopes backwards at an angle of 5° to prevent the contents from falling out of the cups, is mounted on a shaft which protrudes through the back of the furnace chamber to the driving mechanism. The shaft is driven by a ¼ h.p. electric motor, and indexed in 12 positions by an air-operated cylinder. The distance between the end of the cups and the front of the furnace may be varied by means of a screw mechanism operated with a handwheel.

In the centre of the furnace front is a gas burner whose flame plays on a refractory cone cast in the centre of the spider. The angle of the cone is designed to give optimum heat circulation in the furnace. Interchangeable burners can be supplied for the various uses to which the furnace may be put. A square aperture on the furnace front acts both as a loading hatch and as a flue. An air curtain directs the spent gases up a water-cooled chimney.

After the furnace has been brought to a working temperature, which takes about two hours from cold, the operator loads the cup behind the hatch with the pieces to be heated. Pressure on a knee switch causes the spider to turn to the next indexed position, the operator loads the next cup, presses the switch, and so on until all 12 cups are full. By now the pieces first loaded will have been in the furnace for upwards of two hours, and after the next press of the switch they may be removed and transferred to the rolls. The distance from the centre of the hatch to the side of the furnace chamber is only 13 in., so that a minimum of heat will be lost in transferring the work. When the cup has been emptied, it is re-loaded before the next cup is brought into position. It will be noted that as the charges are carried round the furnace each will turn relative to the others, and perfectly uniform heating is thereby ensured.

Gas-fired vertical rotary continuous furnace for heating stainless-steel rods



Sieving metal powders

A serious difficulty formerly frequently encountered in the processing of some metal powders was the clogging and blinding of the mesh during sieving operations. This was due to the fact that, as the particles of certain metal powders have an elongated cuneiform shape, the motion of the shaker screen caused the oversize pieces to become wedged in the screen into which they were firmly hammered by the bouncing action of the rest of the material being sieved.

This difficulty has now been overcome by the application to the screen of the principle of gyratory motion on a horizontal plane which not only eliminates the bouncing action of the particles, the main cause of the clogging of the shaker screen, but also enables the operator to achieve greatly increased throughputs of sieved material through screens of a fine mesh and relatively small surface.

Russell Constructions Ltd., of 9 Adam Street, London, W.C.2, who were the British pioneers of this principle as applied to straining and sieving operations, have marketed a number of machines, among the latest being the Cascade machine, which combines the high-capacity and non-blinding properties associated with the gyratory screen principle with the automatic and continuous rejection of oversize material.

The machine consists of three superimposed circular screens vibrating with a gyratory motion, which causes the particles of the material being sieved to radiate outwards in a curved path. On coming in contact with the first screen a certain number of the fine particles passes through it and goes down a central tube to the discharge outlet. The remainder of the material passes over the edge of the screen and, falling on to the sloping surface of the transfer funnel, is directed to the centre of the second screen. More of the fine particles pass through this screen to the outlet, while the coarser material travels in the same manner over the edge to the centre of the bottom screen. By the time the material has reached the outer edge of this screen all the finer particles have been separated and the coarse material remaining passes off through a gutter to the reject outlet which is on the opposite side to the main discharge outlet.

The machine is powered by a ¾-h.p. electric motor and can be supplied, mounted on a mobile stand or suspended from the ceiling for use where material is stored in an upper storey of a building and fed by gravity through an aperture to the lower parts of the establishment. The gyratory unit is accurately balanced so that no vibration is transferred to the static part of the machine.

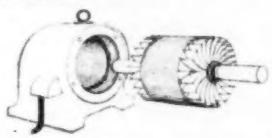
Electrical Aids in Industry *Data Sheet* **No. 14**

Electric Motors & Controls-1

Most manufacturers today employ electric power through individual drives, which permit the right type of motor to be used for each machine. The range of motors available is very large and the factory executive could well be guided in his choice by the expert views of the motor manufacturer, the installing engineer or his Electricity Board's engineer. The characteristics of the main types of motor are summarised below.

Squirrel-cage Motors

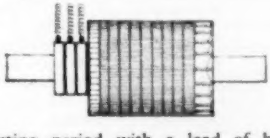
These are the most straightforward and simple in design, and are therefore relatively cheap and robust in character. They should be considered for general duties and in conjunction with variable-speed gears or couplings for applications requiring variable speeds, e.g., for crane drives.



The squirrel-cage motor is very suitable for individual drive of each motion of single-purpose machine tools where the motor horsepower can be precisely specified. It is suitable for driving pumps, fans, lifting hoists and woodworking machines. Textile machinery represents another field of use.

Slip-ring Motors

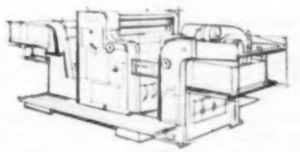
The chief advantage of the slip-ring motor is a very low starting current for a given torque, e.g., full-load torque at starting with a current about 10% above full-load current. This makes it suitable for applications requiring a prolonged



starting period with a load of high inertia. It also permits of speed variation below synchronous speed, though with some loss of efficiency. Typical applications include fans, pumps, heavy lathes, grinders, boring mills, calendering machines and mine hoists.

Three-phase A.C. Commutator Motors

The main characteristic of this type is variable-speed with uniform and gradual acceleration and good efficiency over the speed range. Paper manufacture provides excellent examples of its use, e.g., in reeling, cutting and drying.



A.C. commutator motors are recommended for mechanised bakeries and for cranes and hoists where very slow speeds are frequently needed.

Synchronous Motors

These are constant-speed motors. One particular advantage is that they can be operated at unity or even at leading power factor to correct a system suffering from lagging power factor, and perhaps so qualify for a reduction in the electricity bill. Pump and compressor drives are typical uses to which they can be put.

Single-phase A.C. Motors

In general, single-phase motors are used in light industries for drives not requiring more than about five horsepower or where a three-phase supply is not available. While their use is mainly limited to work of a light nature, they do fill a need in such duties as sewing-machine drives, portable hand tools and window-opening gear.

Direct Current Motors

For an unfettered performance where wide ranges of speed variation are all-important, the D.C. motor is unrivalled. This means the installation of an A.C.-D.C. motor-generator set or rectifier to give the necessary supply, but the increased cost may well be worth while. When variable voltage is applied to the armature, a wider speed range is obtainable than with any other type of motor. Typical applications of the D.C. motor are: cranes, haulage and tippler equipment and high-speed printing.

For further information, get in touch with your Electricity Board or write direct to the Electrical Development Association, 2 Savoy Hill, London, W.C.2. TEMple Bar 9434.

They can offer you excellent reference books on electricity and productivity (8/6, or 9/- post free) — "Electric Motors and Controls" is an example. E.D.A. also have available on free loan within the United Kingdom a series of films on the industrial uses of electricity. Ask for a catalogue.

7914-4

CUT HERE

INSTRUMENTATION

Impact tester for metals

Because of the great amount of energy developed by heavy pendulum impact testers, Testing Machines Inc. now offers a completely safe model which is easy to operate.

The new testing machine has been tried and proven in several nationally recognized laboratories and is now offered to general industry. The tester meets the requirements of ASTM Method E23 and performs Izod, Charpy, and Tension-Impact Tests for metals.

The TMI machine has an automatic electric safety clutch brake, which stops the pendulum after it has made one complete swing. It also has a motorized pendulum return and remote controls. This is an important safety factor and a time-saving factor because it speeds up the next test.

After the pendulum has been arrested, the electric motor with gear head assembly, automatically raises the heavy pendulum hammer to its latched position and the machine is then ready for the next test.

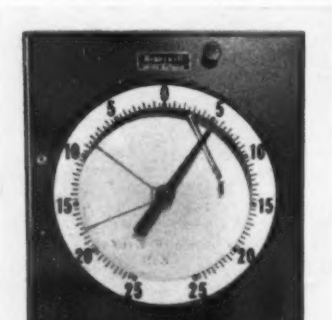
The control panel for operating the pendulum hammer can be located any distance from the machine for safety of the operator or for other reasons.

When testing materials which might shatter and throw fragments, the impact tester can be used with complete assurance that the operator is removed from the danger zone. This machine is also well suited for testing radioactive or other dangerous materials. It already is in use in several laboratories where the control panel is located behind a protective wall to shield the operator.

Here is another most important safety feature. The operator does not have to lift the heavy pendulum after each test. This eliminates a possible cause of bodily injury. The operator cannot be struck by the swinging pendulum during a test or in trying to reposition the pendulum.

For complete information on this modernized impact tester write to the manufacturer:

The manufacturers are Testing Machines Inc., 72 Jericho Turnpike, Mineola, New York, U.S.A.



Temperature controller

Process timers

The latest range of Rodene process timers is of interest to furnace operators because of its great versatility. The '25' series of timers consists of units for single-stage operation giving times from 1 sec. up to 10 min. They reset automatically and thus the dial need only be turned for a new setting. Repetitive timing can be controlled remotely or automatically. This series is powered by a special Rodene motor which always reaches synchronous speed in the right direction in a fraction of a second and automatically declutches when switched off. All units are fully tropicalized and are available for board, through panel or flush mounting. They have a variety of applications such as for the mixing of substances for an exact period of time.

The '700' Rodene timer is a robust instrument which provides a range of times from 20 sec. to 3 h. or more and can thus be used when longer time cycles are required. It is also fully tropicalized and its dial has a shatter-proof window. Setting is effected by means of a red pointer worked by a knob which is geared down to 3 : 1 for setting accuracy. A black pointer travels towards zero showing the unelapsed time and leaving the red pointer marking the set time. On resetting, the black pointer returns instantly without bounce to cover the red pointer.

For sequential control of processes a series of Rodene multi-circuit cam timers has been developed, the smallest having a range of 1–15 sec. and up to four cams and the largest having a time cycle of one week and up to 24 cams. Most of the units in this series are available with a shunt-wound d.c. motor as an alternative to the synchronous a.c. motor. They are supplied with a sheet-metal cover but are also available with dustproof, weatherproof or flameproof covers. Pilot lights, contactors and other subsidiary components can be fitted.

Rodene process timers are manufactured with standard motor windings for operation on any voltage up to 450 and at frequencies from 40–60 c./s. They are used, for example, to control the loading and unloading and the actual processing of billets of steel or aluminium whilst in the furnaces and also to control the inlet of special inert gases to prevent oxidization of the metal.

Further information may be obtained from D. Robinson & Co. Ltd., Gunnersbury House, 717 London Road, Hounslow, Middlesex.

High-precision temperature control

A new, fully transistorized, printed-circuit amplifier-relay for use as a stable, sensitive, temperature controller, has been introduced by Honeywell Controls Ltd.

With the appropriate thermistor temperature sensor, the R7079/7081 Versa-Tran can be used for control in the range of $-60°$ to $+500°$F. with a differential of 1·5 or 0·3°F. depending on the model. Control is very stable and errors due to ambient temperature conditions are easily compensated for by means of a calibration dial.

Wiring between sensing element and relay need not be shielded; the bridge presents no capacity balance problems; ordinary 18-s.w.g. two-conductor insulated cable will suffice.

The control, which incorporates the load relay, can be used up to 300 ft. from the thermistor and operates from the 240-V. 50-c./s. supply.

Versa-Tran controllers are available for surface mounting, flush mounting, or mounting in most electrical enclosures. For full details, specification S1010-6 is available on request from Honeywell Controls Ltd., Ruislip Road East, Greenford, Middlesex.

Classified Advertisements

FIFTEEN WORDS 7s. 6d. (minimum charge) and 4d. per word thereafter. Box number 2s. 6d. including postage of replies. Situations Wanted 2d. per word.

Replies addressed to Box Numbers are to be sent, clearly marked, to Metal Treatment and Drop Forging, John Adam House, John Adam Street, London, W.C.2.

SITUATIONS WANTED

DROP FORGING.—ASSISTANT WORKS MANAGER, experienced in drop, press and upset forging, coining and spark machining, die shop trained. Seeks progressive position in drop-forging firm. Box DF 133, METAL TREATMENT AND DROP FORGING.

SITUATIONS VACANT

METALLURGIST required in the laboratory of a light engineering company to assist in the investigation and development of new materials and processes in connection with the manufacture of diesel engine accessories. The post offers good opportunities to a person who has had a sound general training in metallurgy, gained either through experience in industry or by attending a recognized course. Applicants should preferably be in the age group 21-25, qualified at least to O.N.C. level and prepared to study for higher qualifications. Good pension scheme. Five-day week. Write in full to Staff Employment Officer, C.A.V. Ltd., Warple Way, Acton, W.3.

MACHINERY WANTED

REQUIRED URGENTLY. Secondhand Massey, preferred drop hammer—10 cwt. capacity, also trimming press. Box RE 131, METAL TREATMENT AND DROP FORGING.

MACHINERY FOR SALE

MERCURY ARC RECTIFIER, 70 kW., Hackbridge Trailer-mounted, weatherproof. A.C. 415 volts, 3 phase, 50 cycles. D.C. 230 volts. Complete Unit, ready for service. Whitefield Machinery & Plant Ltd., 48 Chatham Street, Edgeley, Stockport.

An exceptionally good secondhand Ross-Rigby 15-cwt. Electric-Pneumatic Hammer with 'C'-type frame. Hammer cylinder 17-in. diameter with self-contained compressor. With 5¾ tons anvil block. Details and price from:

REED BROTHERS (ENGINEERING) LIMITED

Replant Works, Woolwich Industrial Estate,

London, S.E.18 Tel.: Woolwich 7611 (6 lines)

EDUCATIONAL

**LANCHESTER COLLEGE OF TECHNOLOGY
COVENTRY**

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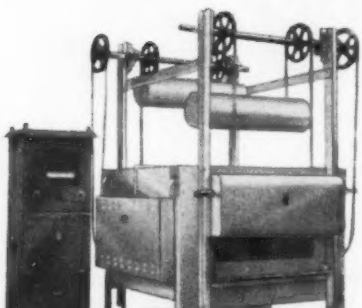

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